HULTEEN

Constructive Features of the American Locomotive

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CONSTRUCTIVE FEATURES OF THE AMERICAN LOCOMOTIVE

BY

Victor Emmanuel Hulteen

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
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VICTOR EMMANUEL HULTEEN

ENTITLED CONSTRUCTIVE FEATURES OF THE AMERICAN LOCOMOTIVE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

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PREFACE.

In presenting "The Constructive Features of American Locomotives" as a thesis, the writer is aware of many difficulties in the work. In the first place locomotive construction is so varied and so many different methods are used, that only a few of the constructive features can be dealt with in a work of this class. To deal with the constructive features of the locomotive as fully as might be is not in the power of the writer, and beyond the space and time allowed for a thesis. The utmost that can be done, is to give the principle constructive features of modern American locomotives. Furthermore, this work will only deal with the steam locomotive, for to deal with electric or other locomotives would only complicate the work, besides they they belong to a different class of locomotive power.

It is largely due to my experience as a

special apprentice, in the locomotive repair shops of the Chicago, Burlington and Quincy Railway Company, that I became interested in this work, so chose this for my thesis. The best of my knowledge in this line was obtained while working around the locomotives of the above shops. This experience was good as far as it went, but only extended with the locomotives of the above road. Consequently I have studied these locomotives more throughly than locomotive belonging to other roads, for it is by working around a machine that we may study it more carefully. Other locomotives and their constructive features, of a different class than those used on the above road, I have gotten from railway magazines, technical papers and books on locomotives and by studying the locomotives about the country as I have had occassion to. If the description and sketches are not treated as they should be, it is the fault of the writer, or from incomplete ideas gotten from sketches and descriptions in technical magazines.

A.
Locomotive Boilers.

1. History.

Of the earlier types of locomotive boilers, the boiler used on Stepenson's locomotive, "The Rocket" built in 1829, will be briefly described. A sketch of this boiler is shown on page 66. While this locomotive is not of American production, there are many constructive features about it that correspond to some of the constructive features of the modern locomotive boiler. The boiler was cylindrical, with flat ends; it was six feet long and three feet in diameter. The upper half of the boiler was used for steam space and the lower half for water and fire tubes, which consisted of twenty five copper tubes three inches in diameter. The firebox was three feet high by two feet wide and was attached on behind the boiler, and also surrounded by a three inch water space communicating with the boiler.

Thus we see, Stephenson had some of the principle constructive features of a modern locomotive boiler.

Other earlier locomotive boilers that deserve

mention, are the first four boilers used on the first four locomotives of American construction.

The drawing on page 67 shows the boiler used on "Tom Thumb", the first American locomotive built by Peter Cooper in 1830. This boiler was upright, and was so small that no natural draft could keep up steam; so Mr. Cooper used a fan geared by a belt to one of the main drivers. Mr. Cooper used gun barrels for tubes, for the want of regular tubes. These were placed above the furnace, which occupied the lower section. No diamension of this boiler have been saved, and the boiler itself has been destroyed; so the size of the boiler cannot be given here. But from pictures of it, the diameter could not have been over twenty inches by four or five feet in hight.

The next type of locomotive boiler is shown on page 68. This boiler was used on "The Best Friend" in 1830, the first American locomotive to be used for actual service on a Railroad. The outside of the boiler can readily be seen from the figure. Of the inside form there are no drawings, and the following description taken from a book will give the reader some idea of the

construction of boiler:- "The boiler was a vertical one, in the form of an old fashioned porter house bottle, the furnace at the bottom surrounded with water, and all filled inside of what we called teats, running out from the sides and top, with alternate stays to support the crown of the furnace; the smoke and gases passing out through the sides at several points, into an outside jacket, which had the chimney on it."

Thus we see, neither of the first two American locomotive boilers had the form of the modern type, while the construction of the second one was peculiar and unlike modern practice in upright boilers.

The third American locomotive boiler, built in 1831, began to take the form of modern practice. This boiler was on "The West Point," the second locomotive built in the United States for actual service on a Rail road. A sketch of this boiler is shown on page 69. This boiler had a number of tubes about three inches in diameter, which were six feet long. Other diamensions are not at hand; so cannot be given here. The fire box was surrounded by water. This

boiler had a front end as shown in the sketch, but as to what the inside form was like, no descriptions or drawings were found.

The boiler of the next locomotive is shown on page 70. This locomotive was the "De Witt Clinton", built in 1831. The boiler, which resembles an old traction engine boiler, had copper tubes 2½ inches in diameter and about six feet long. The fire box was surrounded with water.

A few of the early locomotives were made with vertical and other peculiar types of boilers. Most of them, however, had horizontal boilers, which have been gradually developed into the modern types.

2. Modern Types.

a. Introductory

Modern locomotive boilers all belong to the horizontal multitubular class, with internal fireboxes. There are at the present time, five classes of boilers in general use: the straight-top, the Belpaire, the wagon-top, the extended wagon-top, and the wide firebox. Besides those there are: the water tube firebox and a few special types of boilers, but they are of recent construction, or not in general use. Each type has its advantages, depending on service, character of fuel and water used.

b. Straight Top Boiler.

Page 15 shows an outline drawing of a boiler of this class. This is one of the earlier types of modern locomotive boilers and is used extensively at the present time. The crown sheet of this boiler is stayed by crown bars connected to the boiler shell by means of sling stays, or it may be stayed by radial stays in case the crown sheet has a curved form similiar to

the outer firebox sheet. The firebox is surrounded by water on the four sides. The firebox and outer firebox sheets are riveted at the bottom to a mud ring, which forms the bottom of the water legs. This type of boiler was first made with the narrow firebox, but is now made with both narrow and wide fireboxes. It is also made with a straight or sloping back over the firebox.

C. Belpaire Boiler.

This boiler is illustrated on page 16. This construction was made so as to have crown sheet and outer firebox shell parallel, and thus have the stays at right angles to the sheets. It also adds considerable steam space to the boiler. The crown sheet is stayed to the outer shell by ordinary stay bolts, as are also the walls of the firebox to the outer shell. The outer sheets above the crown sheet are stayed by means of rod stays running across the boiler. This type of boiler is made in various forms: narrow or wide firebox, straight or wagon-top. The earlier types of this boiler were made with narrow fireboxes, but they are

now superseded by the wide firebox.

d. Wagon Top Boiler.

The figure on page 17 illustrates this type of boiler. It has a shell over the firebox much higher than the cylindrical part of the boiler. The larger part tapers, as shown, to its connection with the shell ahead of the throat sheet. The dome is located above the firebox. The crown sheet is supported by means of crown bars, which in turn are supported by means of sling stays.

This boiler is the original form of the wagon top type. Boilers of this kind are seen on some of the older locomotives, but are seldom used in modern construction. The extended wagon top has superseded the original form in modern construction.

e. Extended Wagon Top.

Page 18 illustrates a boiler of this type. This boiler is very similar in construction to the wagon top boiler. As seen in the figure, it has a main shell elevated above the waist of the boiler, to which it is attached by a slop-

-ing sheet. The object of this construction is to increase the steam space, and to have the raised part farther to the front than in the original wagon top, so as to provide space ahead of the crown sheet for the steam dome. The earlier boilers of this type were made with narrow fireboxes, but they are now generally made with wide fireboxes, as the latter are better adapted for burning bituminous coal. The figures on pages 18 & 20 illustrates the narrow and wide fireboxes. This type of boiler is sometimes made with the Belpaire form over the firebox.

f. Wootten Boiler.

The original or Wootten type of wide firebox boiler was invented by Mr. Wootten in 1877. It was invented to meet the demands for a boiler having a larger grate area than was practicable with the older types of boilers at that time. The larger grate area was neccessary for the use of burning anthracite coal, which must be burned with a much slower rate of combustion per square foot of grate surface, and at the same time must be burned

with a much thinner fire. Therefore this type of boiler is used extensively in the anthracite coal districts. The fire box was made as long as practicable, its lenght being determined by the distance a fireman can shovel coal with accuracy and without too much exertion. The large grate area, also, allows a much lighter draft to be used, which is necessary in burning fine coal, as otherwise the small fuel used will be drawn into the flues without being burned.

This boiler is illustrated on page 19. The firebox is made so wide as to make it necessary to place the cab ahead of the firebox for the use of the engineer, and to have a smaller one on the rear for the use of the fireman. The firebox is made very shallow, but very long and wide. (A boiler of this type of recent construction contained the following diamensions:- width 108 1/4", lenght 126 1/8", which gives a grate area of nearly 96 sq. ft.) Two firedoors are provided for a boiler of this class. The firebox is very shallow, so that its sides may go over the rear drivers, and

which is also better adapted for burning the fuel it uses.

This boiler has been used many times for burning bituminous coal, but without success, because of the shallow firebox and the excess grate area. This led to the introduction of wide fireboxes, having a greater dept and somewhat narrower than the Wootten type.

g. Wide Firebox Boiler.

The wide firebox boiler of the modern types was introduced to meet the demands for a boiler having a larger grate area than the narrow fireboxes then in use on bituminous burning locomotives, and a smaller grate area with deeper fireboxes than used on the Wootten boilers. The modern wide firebox was invented in the latter part of the nineteenth century, and have been very successful. They are superseding the narrow fireboxes, as but a very few of the latter are now made.

The wide firebox boiler is made in various styles as: the Belpaire, the straight top, and the extended wagon top boilers.

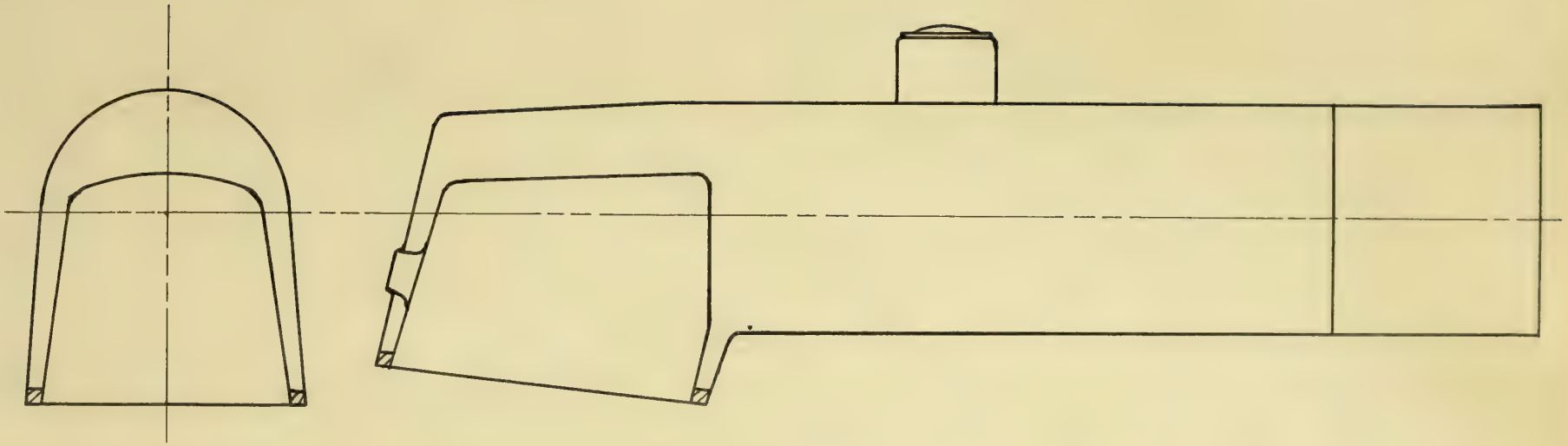
h. Water Tube Firebox Boilers.

Several water tube firebox boilers have been made, but they are not used extensively, because of greater expense in manufacturing and repairing. They are, however, more economical than ordinary boilers. The explanation of this can readily be seen when we consider that over forty percent of the steam is produced by the firebox heating surface, although it contains less than ten percent of the heating surface of the boiler.

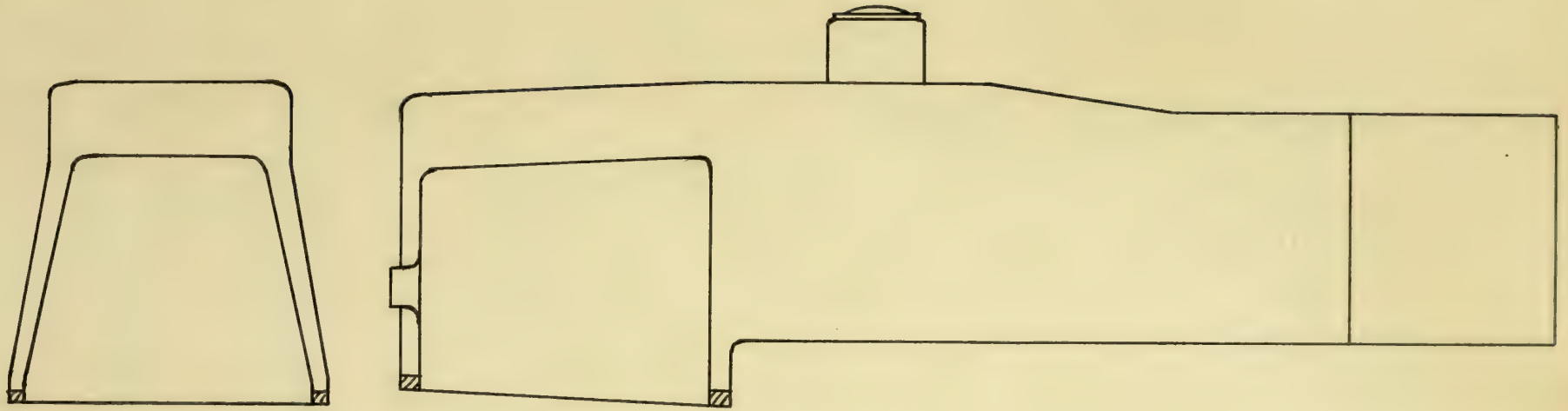
The latest boiler of this type is of recent construction, having come out in the early part of 1906. It was designed by S.S. Reigel, and is illustrated on page 21; from which the construction can be readily understood. It has not been in actual use up to the present time, so nothing as yet can be said in regard to its future use on locomotives. There is no doubt that the water tube firebox boiler will come into more or less use within a few years.

i. Special Types of Boilers.

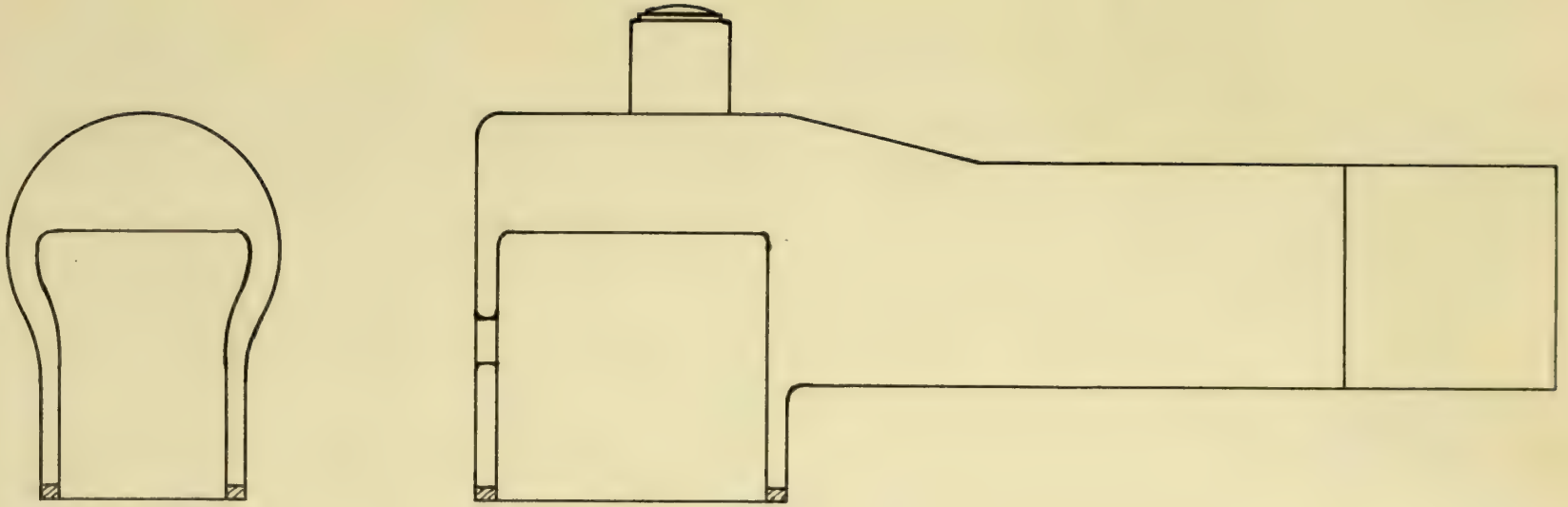
There are a few special types of locomotive boilers including water tube boilers, but they are not used extensively so will not be discussed in this work. Most of these are used on odd types of locomotives, and are seldom seen in locomotive practice. The water tube firebox boiler described under (h) comes under this class of boilers.



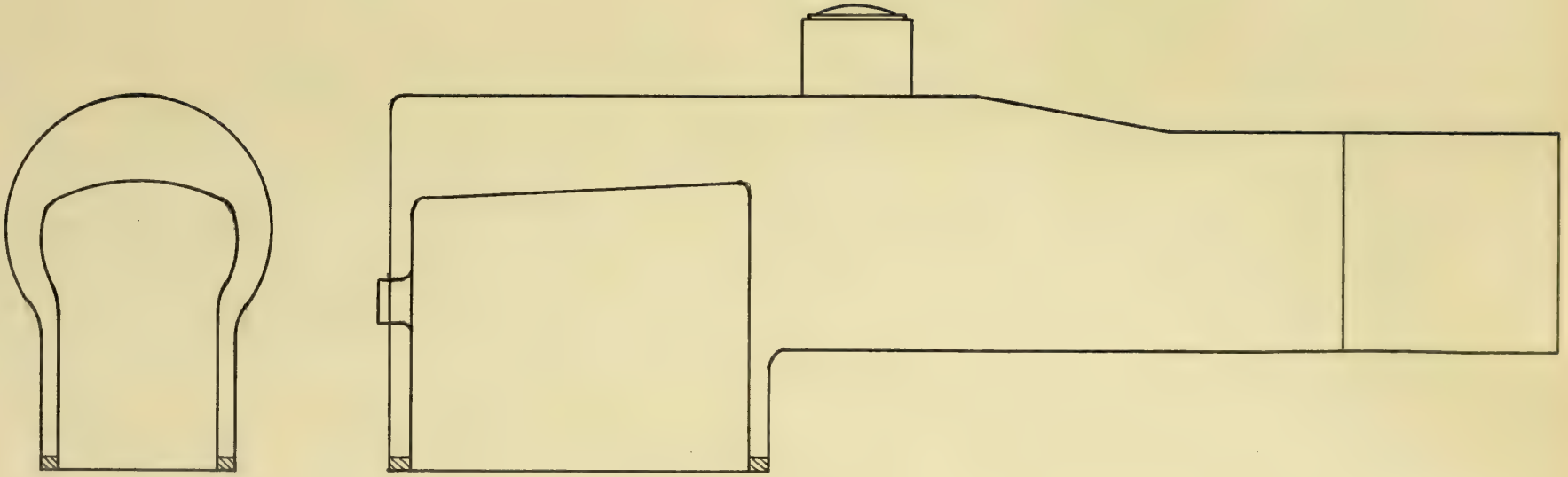
Straight Top Boiler, Wide Firebox.



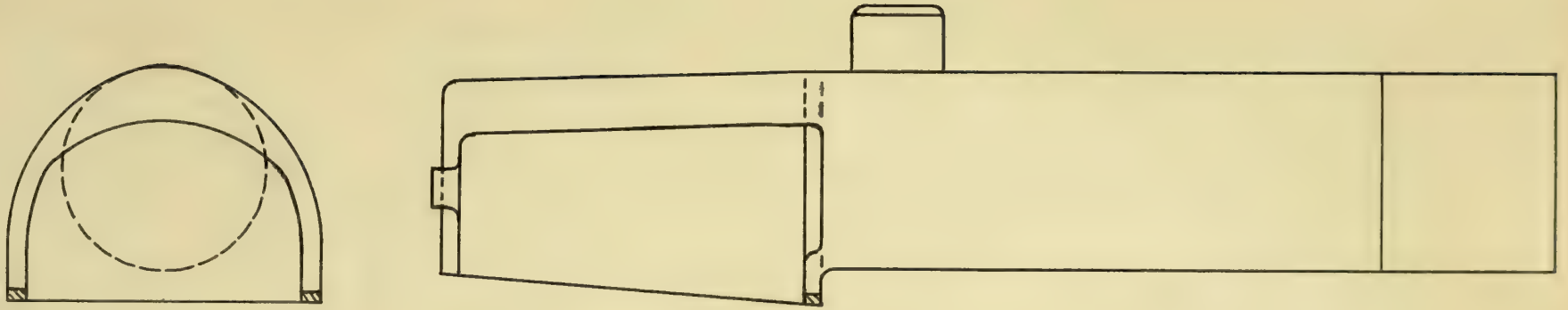
Belpaire Boiler, Extended
Wagon Top.



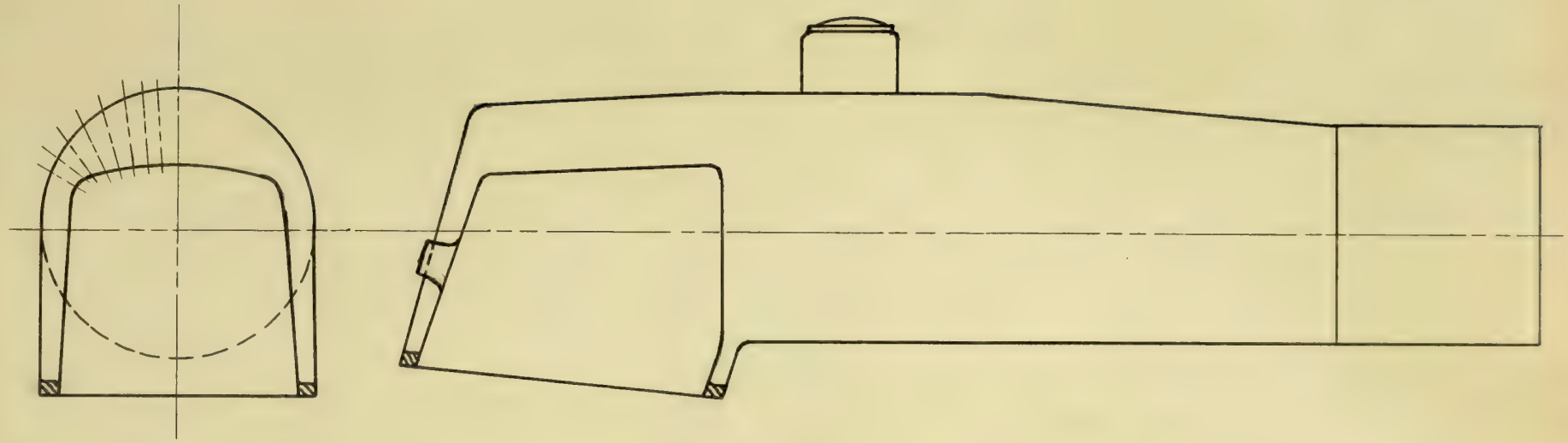
Original Wagon Top Boiler.



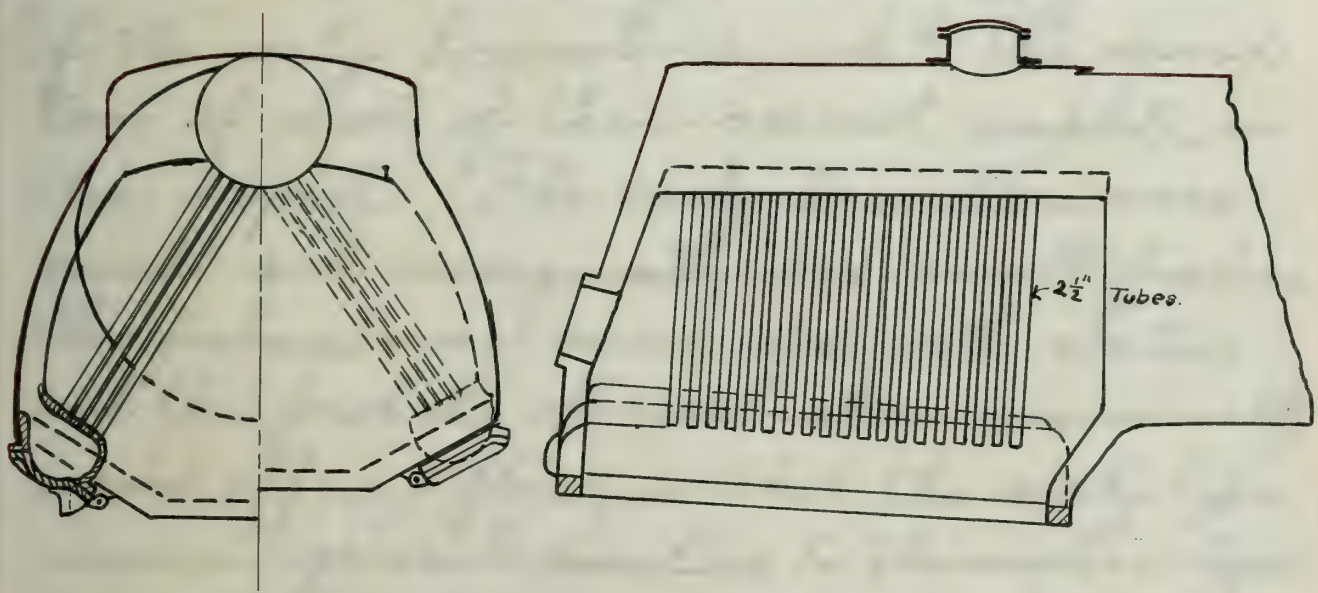
Extended Wagon Top Boiler, With
Narrow Firebox.



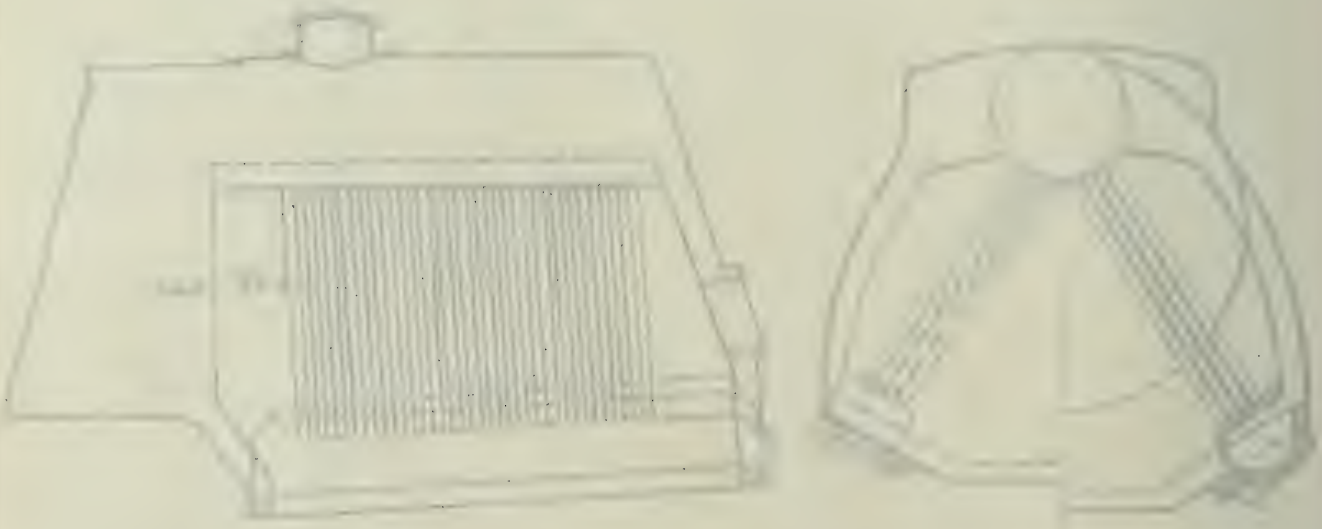
Wootten Firebox Boiler.



Extended Wagon Top Boiler, Wide Fire box.



RIEGEL WATER TUBE FIREBOX BOILER.



3. Construction of Boilers.

a. Fire boxes:-

1. History:-

Little information of a reliable and definite character is to be obtained from technical literature concerning the early history of the locomotive firebox. Few drawings are to be found of the early locomotives, while the description of most of them are not complete in this respect. The early locomotives were small and consequently had small fireboxes. The fireboxes were surrounded with water and the products of combustion were usually carried off by flues, so that the early types were in general similar to the modern types. Some of the earlier types were described under the history of early locomotive boilers, and no further space will be devoted to them. It is sufficient to know that the earlier types were surrounded by water, and that the products of combustion were carried off by flues; thereby having the principle constructive features of a modern firebox.

2. Modern Types.

The modern firebox may be divided into two general classes: the narrow firebox, and the wide firebox. These two classes comprise nearly all the fireboxes in use on modern locomotives.

Narrow Fireboxes.

The narrow firebox illustrated on pages 17-18 was in general use for burning soft coal, until the advent of the wide firebox. This type of firebox may be long or short according to the size of the boiler. For many years the grate area was increased by increasing the lenght of the firebox, until the maximum lenght was nearly reached at which the ordinary fireman could shovel the coal accurately. In 1877 the Wooten boiler came out and superseded it on locomotives to be used in burning anthracite coal, on account of the large grate area of the Wootten firebox. The narrow firebox, however, was used for burning soft, or bituminous coal, until the later part of the nineteenth century; when the modern wide firebox came out, and which was far superior to the old type and the Wootten type, for

burning bituminous coal. The narrow firebox is seldom used in modern construction.

The narrow fireboxes are shown by drawings on pages 17 & 18. These drawings show the principal constructive features of this type. This firebox may be made with either the Belpaire or round top type of boiler.

Wide Fireboxes.

Wide fireboxes may be divided into two classes: the original type or Wootten boiler, and the modern wide firebox. The original type was invented by Mr. Wootten in 1877, and came into quite general use on new locomotives for burning anthracite coal. The drawings on pages illustrates this type of firebox as used in later constructions. The Wootten type has a much larger grate area, than the modern type of wide firebox. This is caused by anthracite coal having to be burned in a much thinner fire than that used in burning the softer varieties of fuel. The modern type of wide firebox was invented to meet the demands for boilers suitable for burning bituminous coal, so as to get a larger grate area; as the power of a

locomotive boiler depends chiefly on the rate and amount of combustion that takes place in the furnace, which is much greater in the wide than in the narrow fireboxes.

Both styles, the Wootten and the modern wide firebox, are made in the round top and in the Belpaire or the flat top type of boiler. Modern construction tends to have the back wall sloping as shown in the figures. The crown sheets in the early types were placed on a level, but modern practice is to have the sheets slope towards the back, the back end being several or more inches lower than the front end.

The Wootten type of firebox was not successful for burning bituminous coal, because the firebox was not deep enough. The modern wide type overcomes this difficulty.

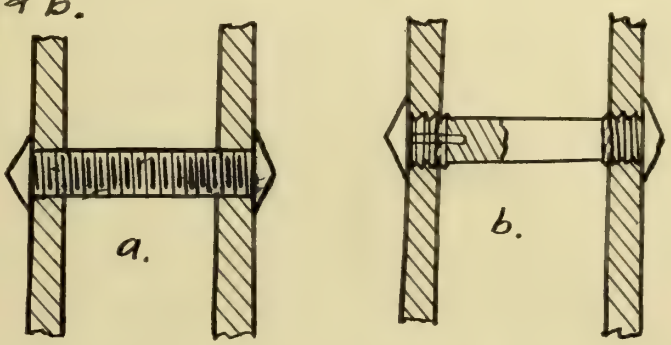
The wide fireboxes are illustrated on pages 15, 16, 19 & 20.

3. Details of Construction.

The locomotive firebox consists of: the back sheet, the back tube sheet, the crown sheet, and the two side sheets. The crown and the two side sheets are sometimes made in one piece. These sheets are made of mild steel of the best

grade suited to the purpose. The firebox is rectangular in shape in a horizontal plane, but in the vertical plane takes the form according to the type of firebox. The sheets of the firebox are surrounded with water, being separated on all sides from the main shell by a space called the water leg; this space ranging from four to five inches in modern practice. The bottom of the water leg is formed by a wrought-iron ring, called the mud-ring, and to which the sheets are riveted. The water legs are subjected to a slightly greater pressure than the rest of the boiler, due to the head of water on it. This pressure tends to force the sides of the firebox inward and those of the outer shell outwards, while the crown sheet tends to press downwards. To enable the firebox and outer shell to overcome this tendency, they are fastened together by staybolts as shown in sketches a & b.

These are made of suitable wrought iron or mild steel, $\frac{7}{8}$ to 1 inch in diameter, and spaced



from four to five inches apart. They may be threaded their whole lenght as shown in (a), or may be threaded as shown at (b). They are screwed into both sheets at the same time, - both holes being tapped with a long tap at the same time -, and the ends are cold riveted over as shown in the figures. The small hole in the end, as shown at (k), is to detect when the stay bolt is broken. Some years ago, these holes extended clear through them, but now only a short hole is drilled into the ends. The crown sheets are stayed by means of crown bars or radial stays. The crown bars may be supported by sling stays as shown in fig. 1, on page 28, or may be supported by the side sheets as shown in fig. 3. The different forms of radial stay are shown on the same page, and can be readily understood from an examination of the drawings.

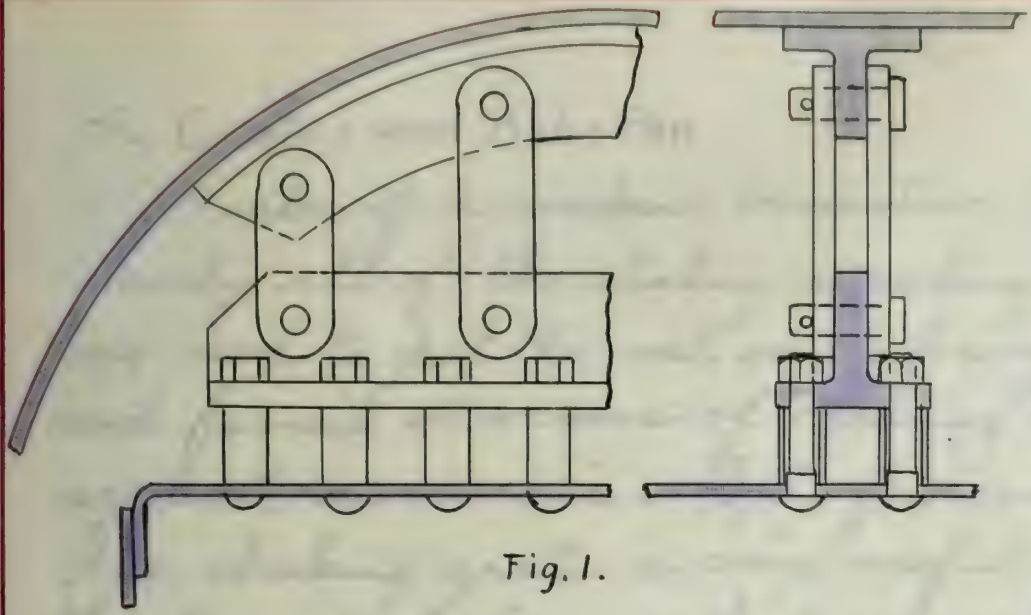


Fig. 1.

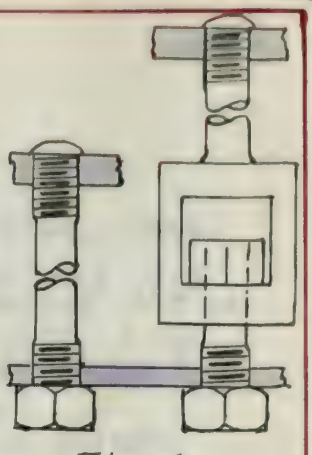


Fig. 4.

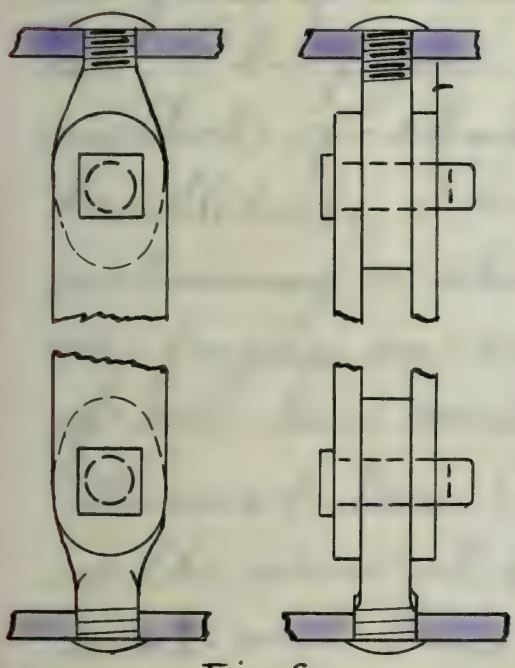


Fig. 6.

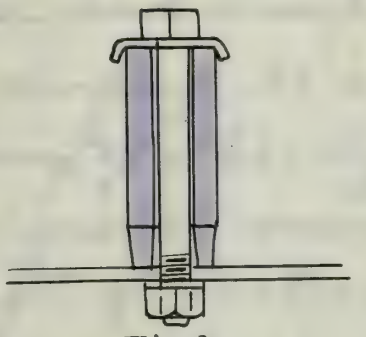


Fig. 2.

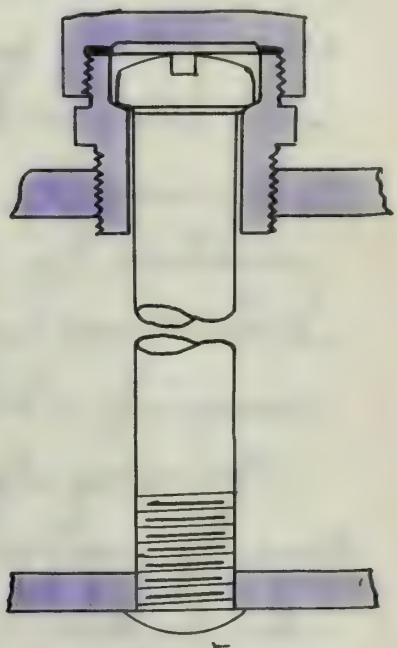
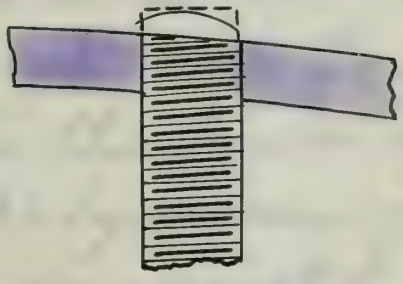
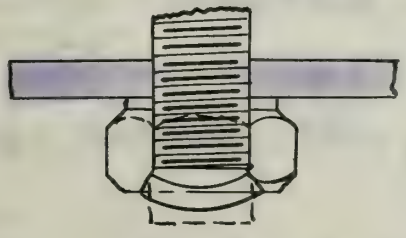


Fig. 5.





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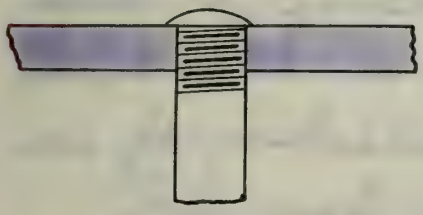


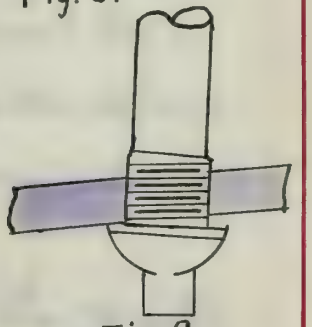


Fig. 9.

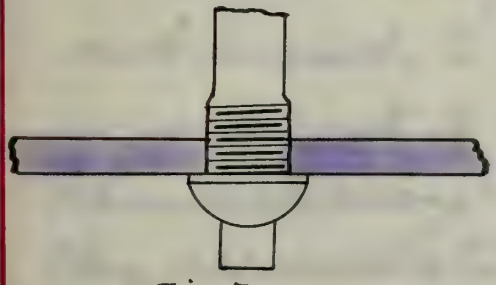
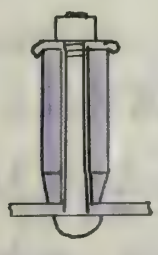


Fig. 7



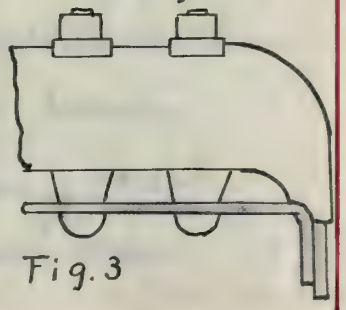


Fig. 3

Fire Box Crown Stays.

Fig 1

Fig 2

Fig 3

Fig 4

Fig 5

Fig 6

Fig 7

Fire Box Crown Stays.

4. Grates and Ash-Pan.

Grates of a modern locomotive boiler are nearly all of the shaking or rocking kind. They are used to put the coal on in firing the boiler, and furnish a means of cleaning the fire as well as an air supply for combustion. The shaking grate is very useful in cleaning the fires of clinkers and dumping the cinders out. The figure on page 37 illustrates the method of shaking the grates by means of handle (a). The grates consist of sections containing a shaft of cast iron on which are fingers as shown at (b). The fingers of one bar meshing in with the fingers of the next bar. On the bar or section of grate, is the arm at (d) by means of which the levers and links are connected, so as to shake the grates. These connections are shown at (a+c). The area between the fingers furnish air for combustion.

The ash-pan comes below the grates, and is used to collect the cinders and ashes in so as not to dump them on the road. There are many forms of ash-pans, as they are made to fit the firebox, and are

governed in their shape by what may come in under the fireboxes such as trailers, wheels, frames and other locomotive parts. Their purposes are the same and all are fastened to the mud ring of the water leg around the firebox, with an air space between the top of the pan and bottom of the mud ring, as this is the only space available for furnishing air for the combustion in the firebox, except the fire door which is not for that purpose. Page 38 illustrates an ash-pan of an old type engine, having an airspace, and two doors for cleaning the pan out. The modern ash-pan is illustrated on page 39, and has two doors from which the ashes and cinders fall and do not need to be raked out, as in the former figure. This ash-pan is made in this shape, so as to clear the axle of the rear trailer wheels, or sometimes the rear driver axle.

The ash-pan is made of thin sheets of wrought iron or steel plates. The doors through which the pan is cleaned are made of wrought or cast iron. The doors are closed and opened by means of levers, and in most

locomotives can only be opened and closed when the locomotive is standing still. The ash pan is fastened to the mud ring by means of studs, and sleeves are used to hold the ash pan from it to arrange for air space.

5. Fire Brick Arch.

The form of the brick arch and its location within the firebox is well shown in the figures on page 38 & 39, which is the furnace end of a locomotive boiler. In the case illustrated, the arch is supported upon studs or angle irons on the side sheets of the furnace. It extends from the back tube-sheet, obliquely backwards. The old method was to support the brick arch upon several water tubes which were fastened into the tube-sheet and back into the back sheet in such a way as to permit of a circulation of water through them. This method is illustrated on page 39, but is now being discarded; and many locomotives having these tubes are now being changed over to the first method, whenever the tubes give out. The first method shown on page 38 is no doubt the best, as no leaky arch

pipes are to be bothered with. The bricks are made heavy, and are now made so that two pieces will cross the firebox. The shape of the firebrick and the method of fastening in is illustrated on page 40. From this figure, the method of fastening in the arch can be readily understood. The bricks are about four or five inches thick and about eight to twelve inches wide, the lenght depending on the width of the firebox, in which they are to be used. They are curved in forme as shown, and their weight must hold them in place on the angle irons at the side of the firebox.

The advantages of the fire arch are:-

1. By its presence, the lenght of the flame way is increased, and particles of fuel are thereby held in suspension for a longer time before entering the tubes; the result being that particles which otherwise would be sparks or cinders are in many cases burned to ash.

2. By its presence, it also serves to distribute the draft more equally over the grate and in so doing it doubtless increases the efficiency of the furnace action to a great extent.

3. Matains a more even temperature in the tubes, and prevents to a great extent unequal expansion and contraction, thereby increasing the life of flues.

The brick arch, therefor, aids combustion, helps to prevent black smoke, increases the life of the tubes, and saves the coal consumption. Arches are not used on hard-coal burning locomotives.

6. Stokers.

Years ago when the locomotive was in its infancy, the firebox was so small, and consequently little coal burned that the fireman had little work in keeping up steam at the maximum capacity of the locomotive. Since then, the locomotive has increased in size until now the capacity of the fireman for shoveling coal is nearly reached. This is readily understood when we consider that the fireman has to keep a furnace, containing from forty to sixty square feet of grate area, covered with coal at the maximum rate of nearly two hundred pounds of coal per square foot of grate area per hour; while the speed of the train may

be very high increasing the difficulty of firing very much. This may, also, be readily understood when we consider that a modern locomotive developes as high as 1,200 horse power at its maximum capacity. This has led many men to consider the use of mechanical stokers to feed boiler furnaces with coal. Many different schemes have been tried, but none of them have as yet succeeded in producing the desired results.

The latest developement along this line is the invention of Mr. Barnum of Montana. He has produced an underfeed stoker, working the coal in the furnace by means of two spiral screws, and having an air tight firebox; the draft and air being supplied to the furnace by means of two fans of peculiar construction. These fans are run at a high rate of speed, by a DeLaval steam turbine; and the construction of them is such that they furnish as much air as two large fans of ordinary construction occupying several times the space, and requiring as much or more power. These fans are placed behind the boiler on the deck of the locomotive; the steam turbines being connected to them by

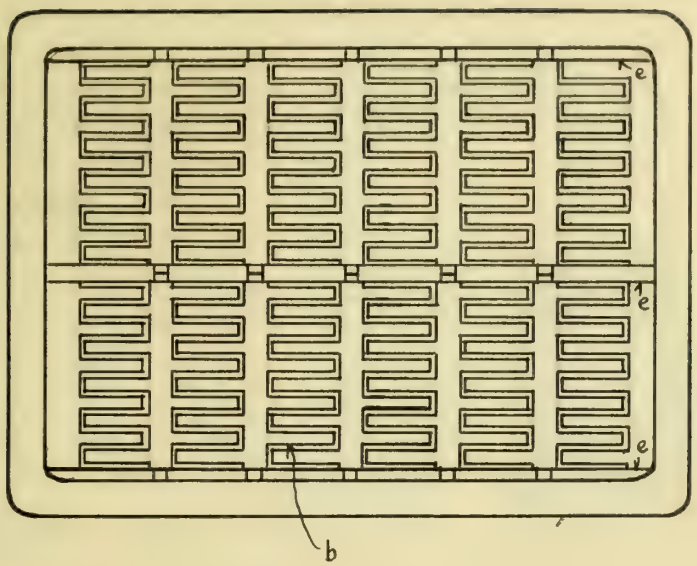
means of a gear, reducing the motion ten to one; the speed of the fans being 2000 revolutions per minute. The power of the steam turbine at two hundred pounds pressure is forty horse power. The coal feeding screws, of which there are two, were run by a special type of rotary engine, placed in front of the firebox and beneath the waist of the boiler. The apparatus of this kind was in operation several times, during the latter part of the year 1905, on the Chicago, Burlington, and Quincy Railroad at West Burlington, Iowa. It gave fairly good results, considering the grade of slack used for fuel, and it being a new contrivance. It was not a success, however, but results no doubt indicated that it might be made successful at some future time. At the present time, the inventor is experimenting and trying it on the locomotives of another road.

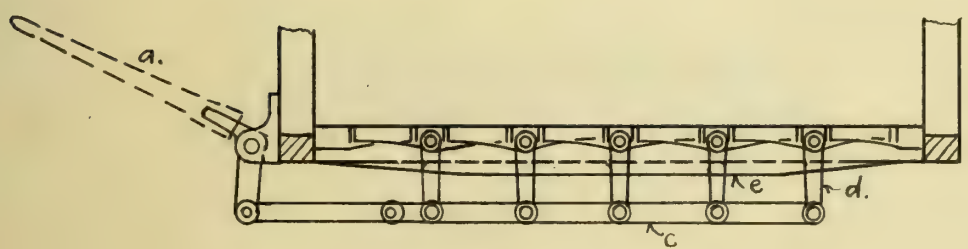
Several other types of stokers have been tried, but without success.

7. Remarks.

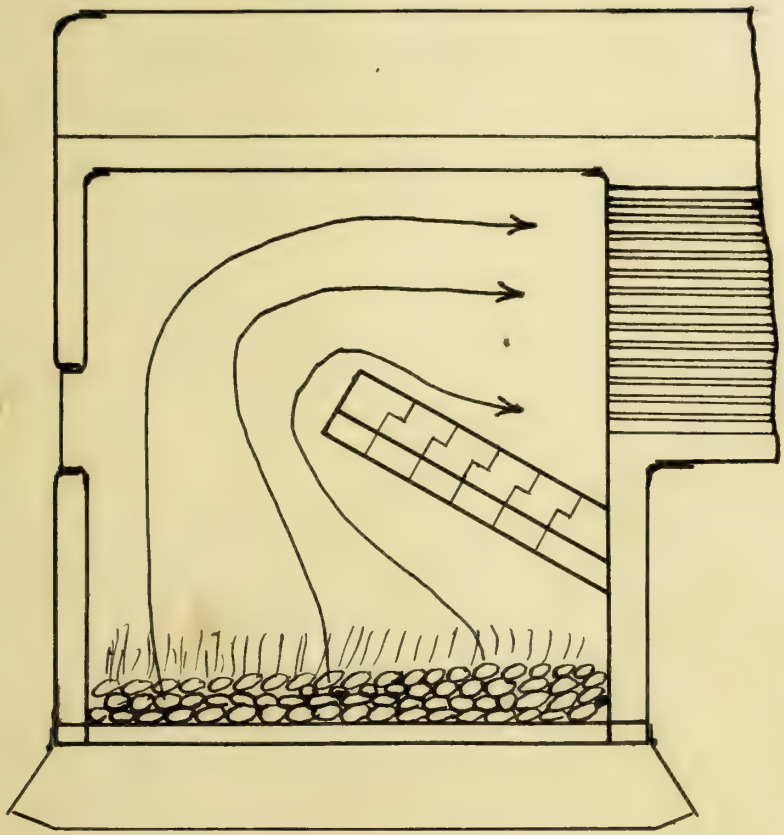
The values plotted on pages 174 & 175 gives the grate areas of sixty five freight engines and sixty two passenger engines of the most notable locomotives built in the United States between the years 1895 and 1905. From these values the tendency in grate area can be seen within the ten years noted. These values show an increase in grate area, the most notable of which is in 1900 or at the advent of the wide firebox.

These values readily show what the various grate areas are for the different classes of locomotives. From this data, it is seen at a glance that the wide firebox has come to stay for the use of bituminous coal as fuel. The values were plotted from the most notable type of bituminous coal burning locomotives, which have been described in the American Engineer and Railroad Journal, between the years 1895 and 1905. The data was taken from one journal, so as not to tabulate the value of one locomotive more than once.

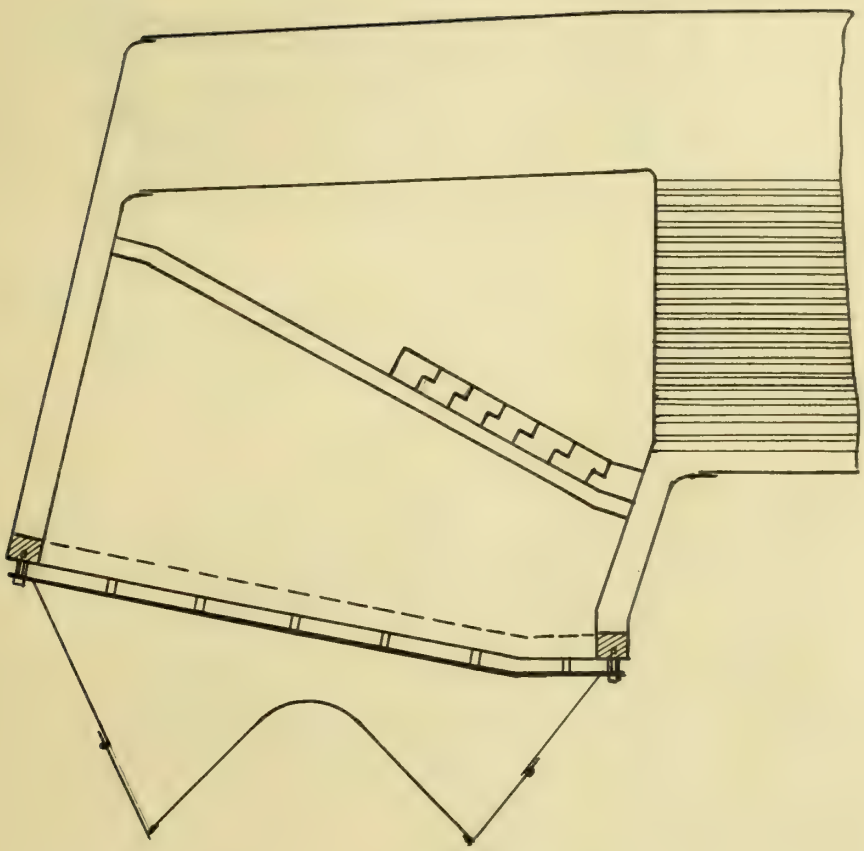




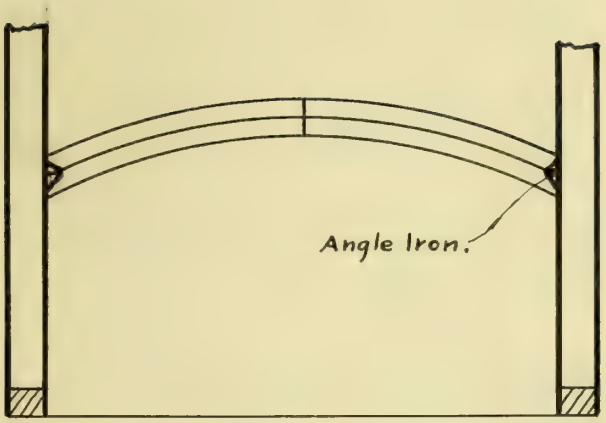
Grates & Shakers.

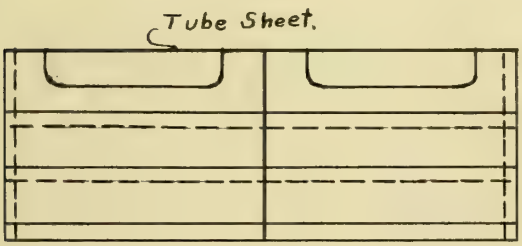


Firebrick Arch & Ash-Pan.



Firebrick Arch & Ash-Pan.





Details of Firebrick Arch.

b. Front Ends:-

1. History.

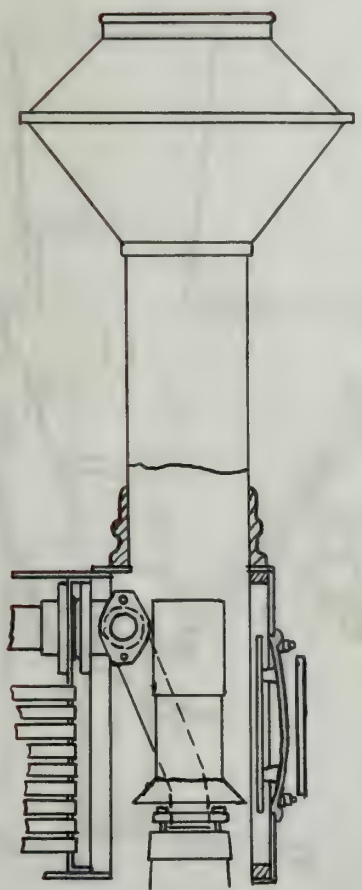
The first American locomotive boiler had no front end for it was of the vertical type, but no doubt, it had a smoke chamber above the tubes, which corresponded to the front end. The only purpose that a front end was used for, in the earlier locomotives, was to furnish a smoke box to connect the flues and chimney. The next American locomotive built had a vertical boiler, and has been described in the "History of the boiler" on page 4. The next American locomotive boiler is illustrated on page 68, which shows a large front end, and which was used as a smoke box only. For many years, the front end was used merely as a smoke box, and it has gradually taken the form of the modern types. The front end has grown from a smoke box to be used as: smoke box; a place for, steam pipes, exhaust nozzle, deflector plate for breaking up pieces of cinders and live coals going through the flues, netting to prevent large sparks and cinders going up the stack, and to collect sparks and

cinders in. The first modern front ends were made short as illustrated on page 43, which can be readily understood from the figure and the description given of the mod-ern, or extended front end.

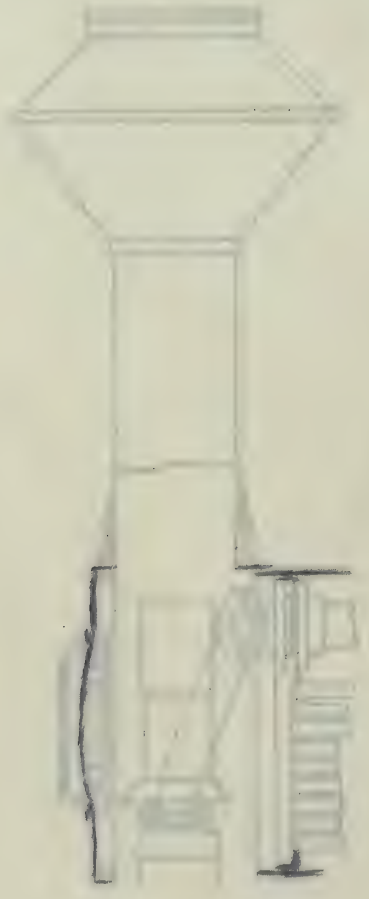
2. Modern Types.

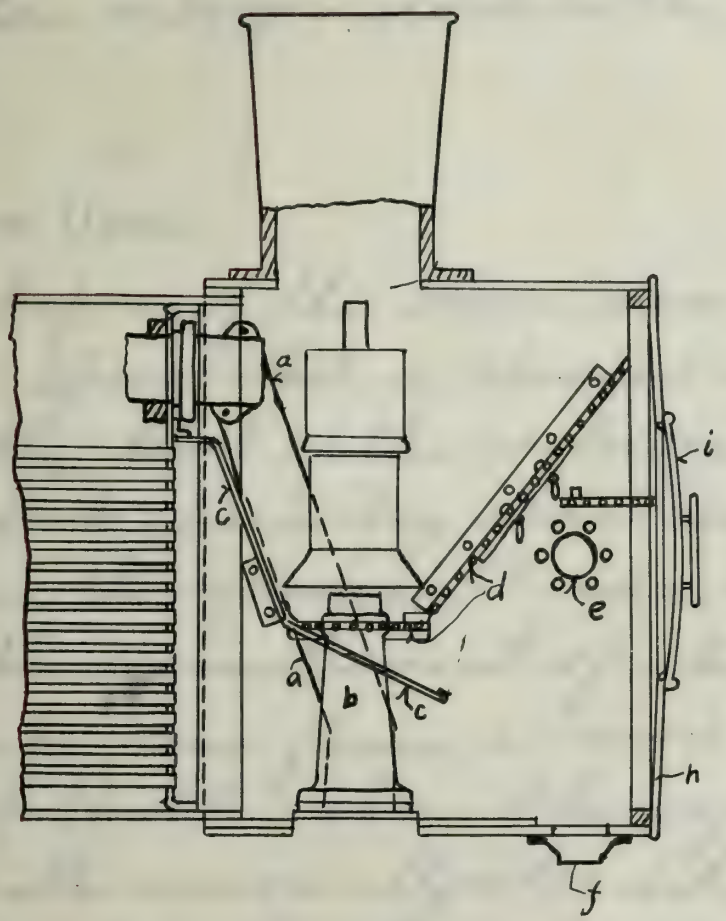
The modern type of front end is a long extension of the main shell of boiler. The figure on page 44 illustrates a modern front end. It contains the steam pipes a, exhaust nozzle b, deflector plate c, netting or screen d. There is an opening e in one side of the smoke box to afford a means of examination. Some extensions have a cinder trap f for removing the cinders from the front end. This and the opening e are made of cast iron, and are made air tight, so as to not disturb the effect of the vacuum caused by the exhaust steam. The front end is covered by a casting h to which is fastened the door i. The door i must be air tight, for if air were admitted to the smoke box, it would partly destroy the action of the exhaust in making a vacuum.

The two figures, also, show the old and the new type of smoke stack. The old type,



Short Front End or Smokebox.





A Modern Extension Front End.

or diamond stack, contained the deflector plate and netting, which is now placed in the smoke box on the modern types. The size of the stack has a great influence on the draft, a small stack producing a fiercer draft than a larger stack on the same locomotive.

C. STeam Dome.

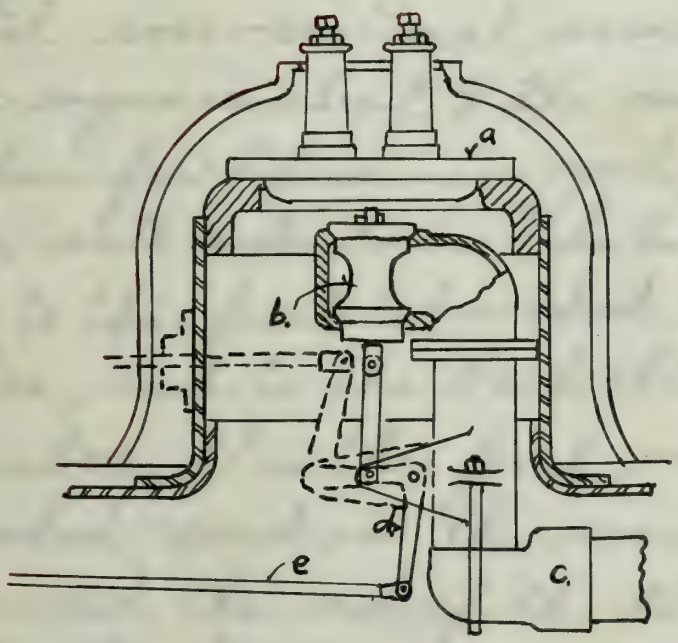
The purpose of the steam dome is to provide a space that is elevated considerably above the level of the water in the boiler, from which space dry steam can be drawn for use in the cylinders. Besides this, the dome adds a small amount of steam space to the boiler, and forms a convenient place to put the throttle valve. The safety valve and whistle are usually attached here also. The dome furnishes the only means of getting into the boiler, as there are no manholes on a locomotive boiler, except at the steam dome cover.

The steam dome is usually placed on the highest part of the boiler, and about midway between the ends of the boiler proper. It is made of the same metal as the boiler

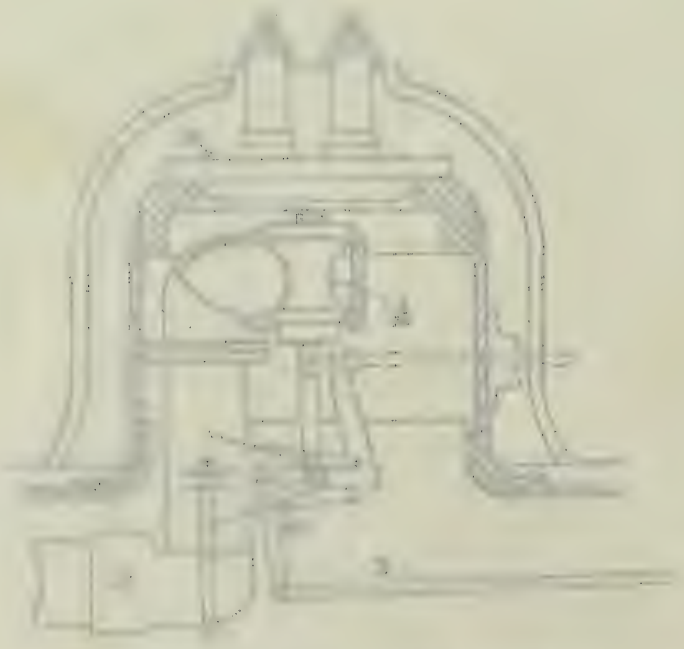
shell, with a cast iron or steel ring at the top as shown on page 47, to which the cover (a) is bolted by means of studs. This cover usually contains the safety valve and whistle as shown. The throttle valve is shown at (b) and its connection to the steam or dry pipe (c). The lever d is to operate the throttle valve with, and the rod e runs through the rear head of boiler, where it is connected to the throttle lever; however, this rod may go through the back side of the dome, as shown by the dotted lines, and the throttle lever placed on top of the boiler instead of back of it. This depends on whether the engineers seat comes back of the firebox, or at the side of it. There are various other types of throttles and connections used, but their general outlines are the same.

d. Tubes.

The tubes of a locomotive boiler are nearly all made of wrought-iron. They are usually made two inches in diameter on the outside of tube. In some cases they are made smaller or larger than two inches. By reducing the diameter more tubes can be put in, thus



Steam Dome-Throttle Valve.



increasing the total tube heating surface. At the same time, however, the tendency of the tubes to become stopped up is increased. Increasing the diameter of the tubes, decreases the total tube heating surface, and reduces the capacity of the boiler. In other words, a small tube has a greater heating surface in proportion to the volume of gases passing through it than a larger tube.

The total cross-sectional area of the tubes in a large engine is about $\frac{1}{8}$ the area of the grate surface for bituminous coal, and $\frac{1}{10}$ or less for ~~for~~ anthracite coal. The tubes are connected to the front tube-sheet in the smoke box, and to the back tube sheet in the firebox. In the front end, the tubes are expanded; and in the rear, they are expanded and the end of the tubes beaded over. Copper ferules are usually placed in between the sheet and tube, so as to make a better joint.

e. Superheaters.

Superheaters in use on the locomotive give greater economy in water than in fuel; in other words, the engine economy is increased while the boiler economy is decreased, due, of course to the additional heat required to superheat the steam, which decreases the heat available for the generation of steam.

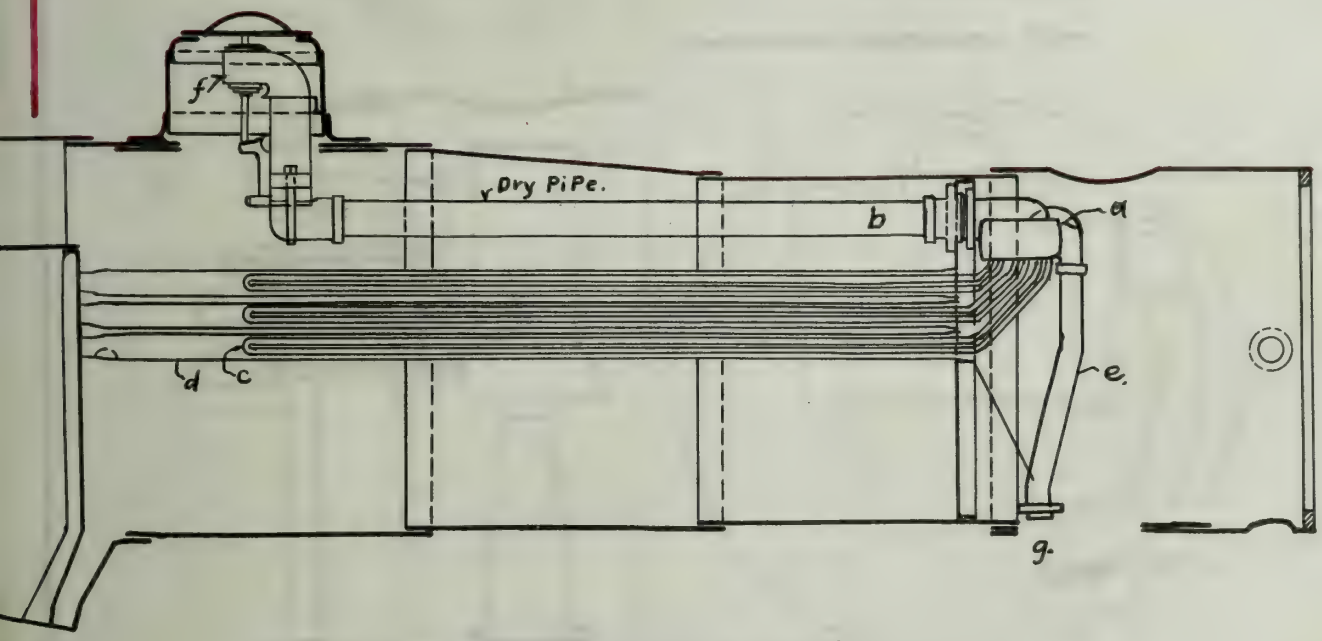
Several different types of superheaters are in use. The most important of these are: the Schmidt, the Schenectady, and the Cole's. The following description gives the method by which each work, as well as their constructive features:-

The Schmidt superheater is shown in detail on page 51; and by a careful study the constructive features as well as the method of working can be readily understood. As shown in the figure, a is the header casting, with two seperate appartments; one for steam from the dry pipe b, and one for the steam after it has passed through the small superheater tubes shown in the figure, and from which it passes on into the steam

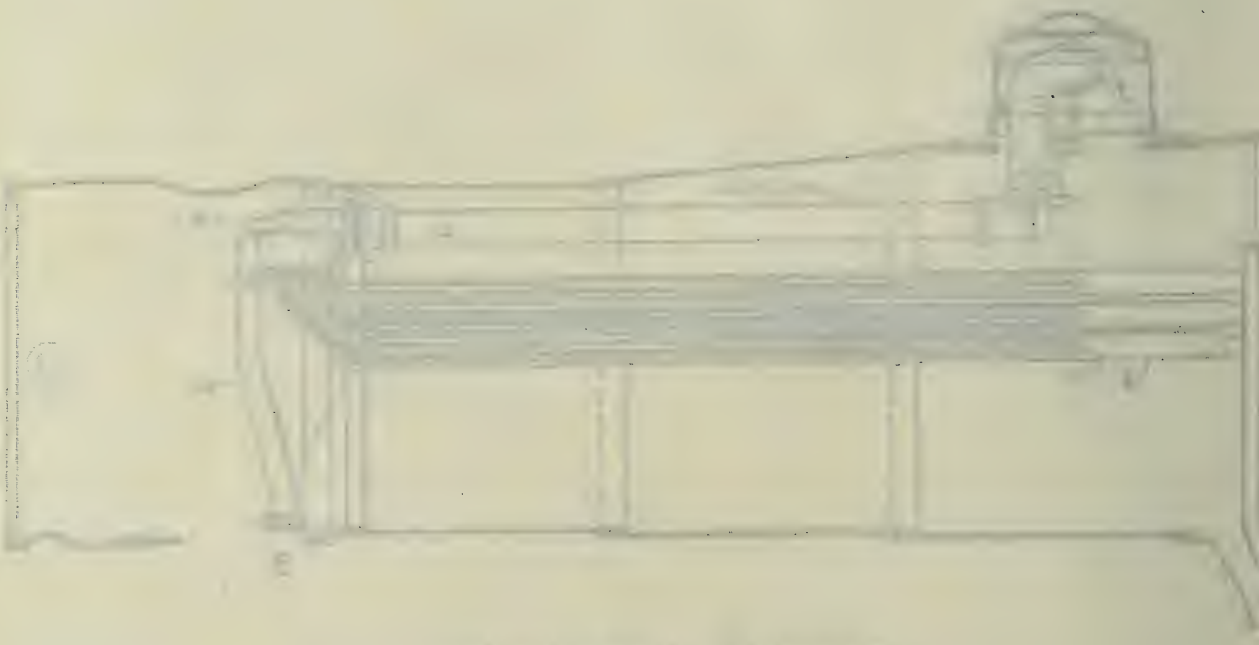
pipes e. The steam enters the throttle at f passes along the dry pipe b into one chamber of the header casting a, then into the small pipes and returns to a and passes on into e and thence into the cylinders. The steam being superheated in the meanwhile by the hot gases passing through the flues. There are twenty two large five inch flues, each containing two return pipes as shown and about one inch outside diameter. The ends at c are placed about three feet from the fire box end.

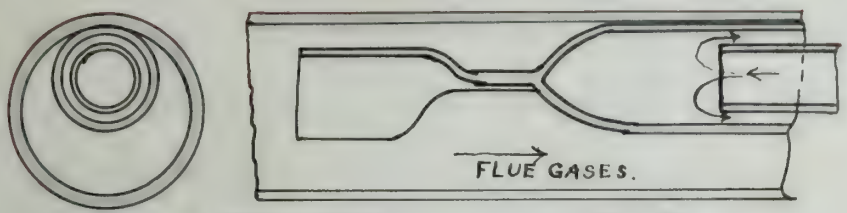
The Schenectady and the Cole's superheaters are in principle nearly the same as the Schmidt's. The only difference being in their constructive features, which can be readily understood from the drawings on pages 52 & 53. The drawing of the Cole's superheater shows the method of construction, so that the pipes may be easily removed for repairing the same. Similar constructions are used on the other two, but are not shown in the drawings.

The results of using superheated steam in the operation of the locomotive give an economy of as high as 30% for water and 10% for fuel with a superheat of 400° F, as compared with

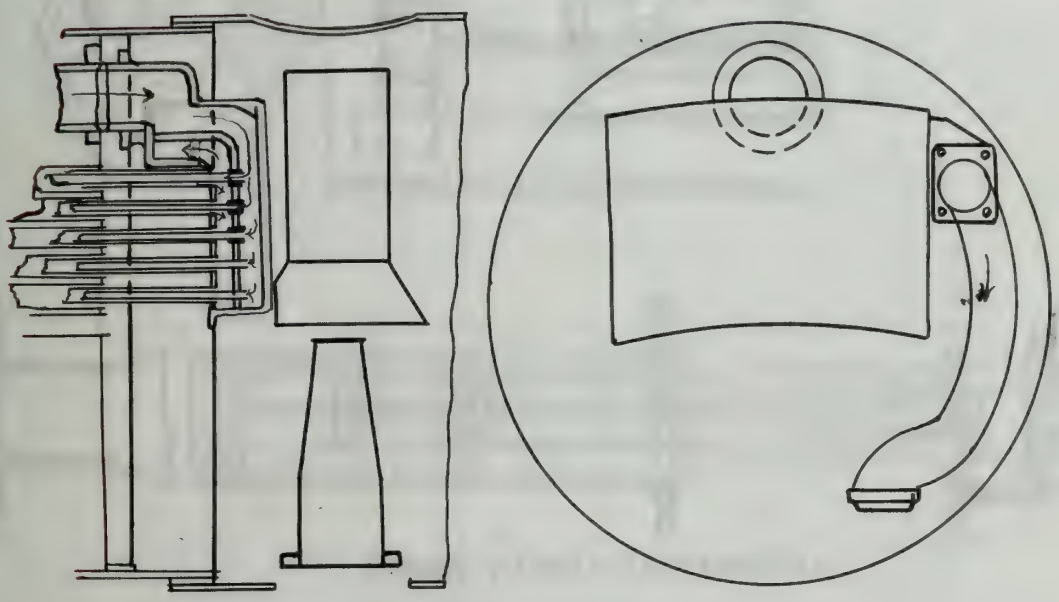


Schmidt Superheater.

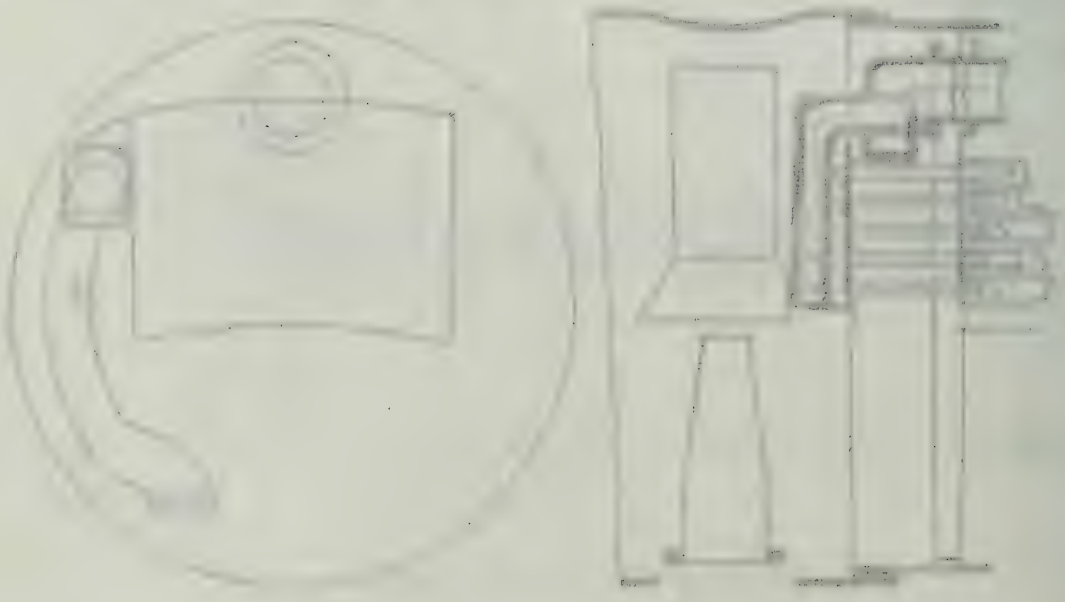


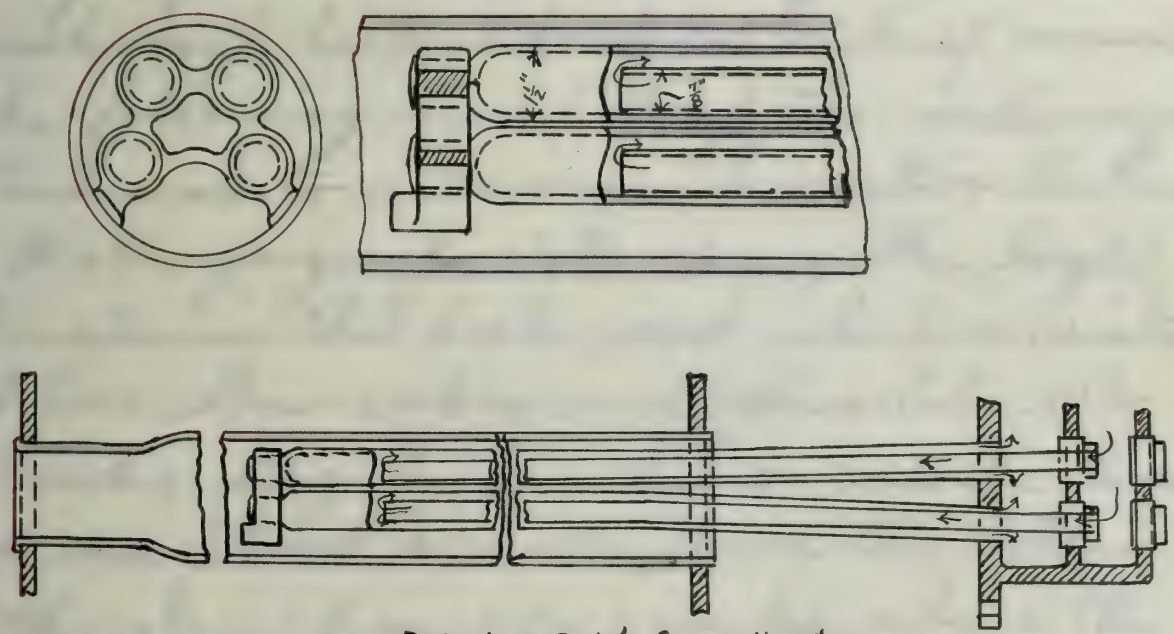


Back End of Superheater Tubes.

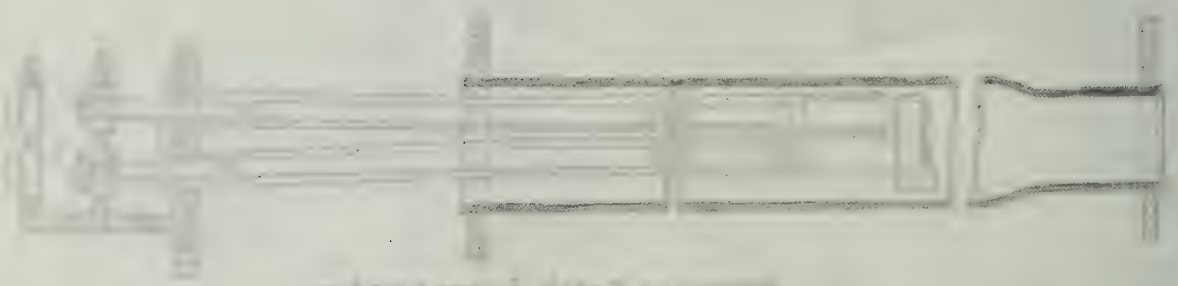


THE SCHENECTADY SUPER HEATER





Details of Cole's Superheater.



locomotives without superheaters.

f. Boiler Attachments.

The various fittings and appliances that are common to all locomotive boilers of modern construction, and which may be grouped under the head of boiler attachments will be considered in a brief manner. The following is a list of the ordinary attachments to a modern locomotive boiler:-

Water gauge for determining the height of water in the boiler; and which consists of two elbow valves and a glass tube 10 to 15 inches long by $\frac{5}{8}$ inches in outside diameter, and placed so as to have the bottom of the glass from 0 to 3 inches above the highest point of the crown sheet. There are sometimes two water gauges on a locomotive; one for the fireman, and one in front of the engineer when he cannot see the gauge glass on the back of the boiler.

Gauge-cocks for determining the height of the water in the boiler; which consists of three brass cocks. The center of the lowest gauge-cock is generally placed 3 inches above the highest point of the crown sheet, although

on some locomotives it is placed as high as 4 to six inches above the highest point.

Steam Gauge to indicate steam pressure in the boiler. It is placed where the fireman can see it, but when the construction of the locomotive is such that the engineer cannot read the gauge from his seat, another one is placed where he may readily see it. These steam gauges are of the best makes, and should give correct readings around the boiler pressure carried. The working pressure carried, which should also be the maximum pressure allowed, should be marked by a red dot placed under the corresponding gauge reading.

Safety Valves are usually placed on the cover of the steam dome as shown on page 47, however, on some locomotives they are placed in a seperate dome sheet as shown on page 141. They are used as a safety against over pressure within the boiler, so as to prevent boiler explosions. Two or three are attached to every boiler, so that if one is inoperative the others will take care

of the excessive pressure and give the allarm to the fireman who will fire more slowly for a while.

Injectors are used to feed water into the boiler. In the early history of the locomotive, pumps were used to force the water into the boiler, but these have been superseded by the injector since its introduction in 1860, by Wm. Sellers and Co., who now supply many of the best injectors for locomotive practice. There are two classes of injectors in use on locomotives: non-lifting and lifting. The non-lifting injector must be placed below the level of the tank bottom, while the lifting injector is placed up on the side of the boiler in the cab. Each locomotive is supplied with two injectors; one on each side, both being of the same kind, or they may be different, that is: lifting and non-lifting.

Other attachments to the boiler are: boiler checks, feed pipes, steam pipes for operating injectors, blow off cocks etc. The boiler checks are screwed into the front end of the boiler, and one on each side; the feed

pipes are attached to these, connecting the boiler with the injectors.

The blow-off cock is attached to the bottom of the water leg near the mud ring, and is usually placed in front of the firebox below the waist of the boiler.

All these attachments are neccessary for the operation of the boiler. Other attachments on the boiler, but not neccessary for its operation are: the air pump and piping valves, etc., the steam heating valves and gauges if the locomotive is for passenger service, the bell ringer, sanding apparatus, lubricators etc.

g. Throttle Valve.

The throttle valve is placed inside of the steam dome as shown on pages 47. In old style of locomotives, however, the throttle valve was placed at the front end of the boiler, or else in the smoke box close to the tube sheet. There are many different forms of throttle valves in use; the one shown on page 47 is a typical type much in use, while many of the others are similar to this one. The valve consists

of two disks of unequal diameters, cast with wings as shown, which act as guides. The lower edges of the disks are beveled and are carefully ground on their seats, so as to make a steam tight joint. There are two reasons for making the bottom one smaller than the upper one: first, by making the bottom one smaller, it can pass through the opening for the upper disk; and secondly, the total pressure on the upper one must be in excess of the total pressure on the under one when the throttle is closed, so as to prevent the valve from opening except by means of the throttle lever.

The throttle lever, which operates the throttle, is placed in the cab on the back part of the boiler, however, this has been discussed under the steam dome and will not be given further space here.

h. Dry Pipe.

The dry pipe connects the throttle, in the steam dome, with the steam pipes of the front end. In other words, the dry pipe, the steam pipes, and the throttle valve serve the same purpose on the locomotive,

as the piping and valves between the boiler and the engine of a stationary plant.

Page 51 shows the dry pipe in position; the throttle valve being connected to one end, and the steam pipes to the other. A T, or "nigger head" forms the connection between the dry pipe and the steam pipes. The dry pipe is made of tubing, and ranges from five to eight inches in diameter, depending on the size of the locomotive.

i. Steam Pipes.

The steam pipes serve as a passage way for the steam from the dry pipe to the cylinders. They are made of cast iron, and are located in the smoke box, as shown on page 51, 52 & 75. They are made to conform quite closely to the shell of the smoke box, for the reason that they then offer the least resistence with the flues, and, when so curved, the ill effects of contraction and expansion are very much reduced.

The joints between the steam pipes and cylinders are made by having a spherical surface for a brass bushing to fit into, and which will adjust itself so as to make

a steam tight joint without having the steam pipe in a fixed position. The joints, between the steam pipes and "nigger head", and the dry pipe and throttle valve are made by the same method.

J. General Remarks.

The boiler shell is made of a good grade of mild steel. The sheets are riveted together with good wrought-iron rivets. The circumferential seams on modern heavy boilers are double lap riveted, while the longitudinal seams are double or triple riveted butt joints. The longitudinal seams are placed on the sides or top of the boiler, and should never be placed on the bottom.

The boiler is lagged to prevent radiation of heat. This lagging is made of various substances; the Chicago, Burlington and Quincy now use a lagging made of equal parts of asbestos, sawdust and lime; other laggings contain a great amount of magnesium, lime and sawdust. The lagging is plastered on the boiler about one and a half to two inches thick, and a sheeting of iron is placed over it called the ~~locomotive~~ jacket.

The locomotive boiler is braced and stayed similar to stationary boilers, except that the very high pressures carried by the locomotives requires much more care in this respect.

The front end of the boiler or rather the smoke box is attached to the saddle of the cylinders by means of bolts fitted into reamed holes. The saddle is fitted to the boiler by being chipped with chisels to the required form. The front end of the boiler is the only place where the boiler is fixed rigidly to the frame of the locomotive. It is braced at other points, but these braces consists of plates and prevent sideways and vertical motion, but have no means of preventing end motion. This construction is employed for contraction and expansion of the boiler, which is nearly $\frac{1}{2}$ inch for lenght of boiler on large locomotives. The back end of boiler is supported by expansion pads, which supports the end of the boiler, and prevents the boiler from moving sideways, and allows it to expand and contract.

In the early locomotives, the pressure carried ranged from fifty pounds upward, - Stephenson's boiler carried fifty pounds, - since

then, the pressure has increased until the maximum pressure carried by modern types of locomotives is now 235 pounds carried by the Mallet compound shown on page The average working pressure today for recent locomotives is around 200 to 220 pounds. The pressures plotted on page 64 shows the pressures carried by the different types of locomotives used on the Chicago, Burlington and Quincy Railroad Co. since 1874.

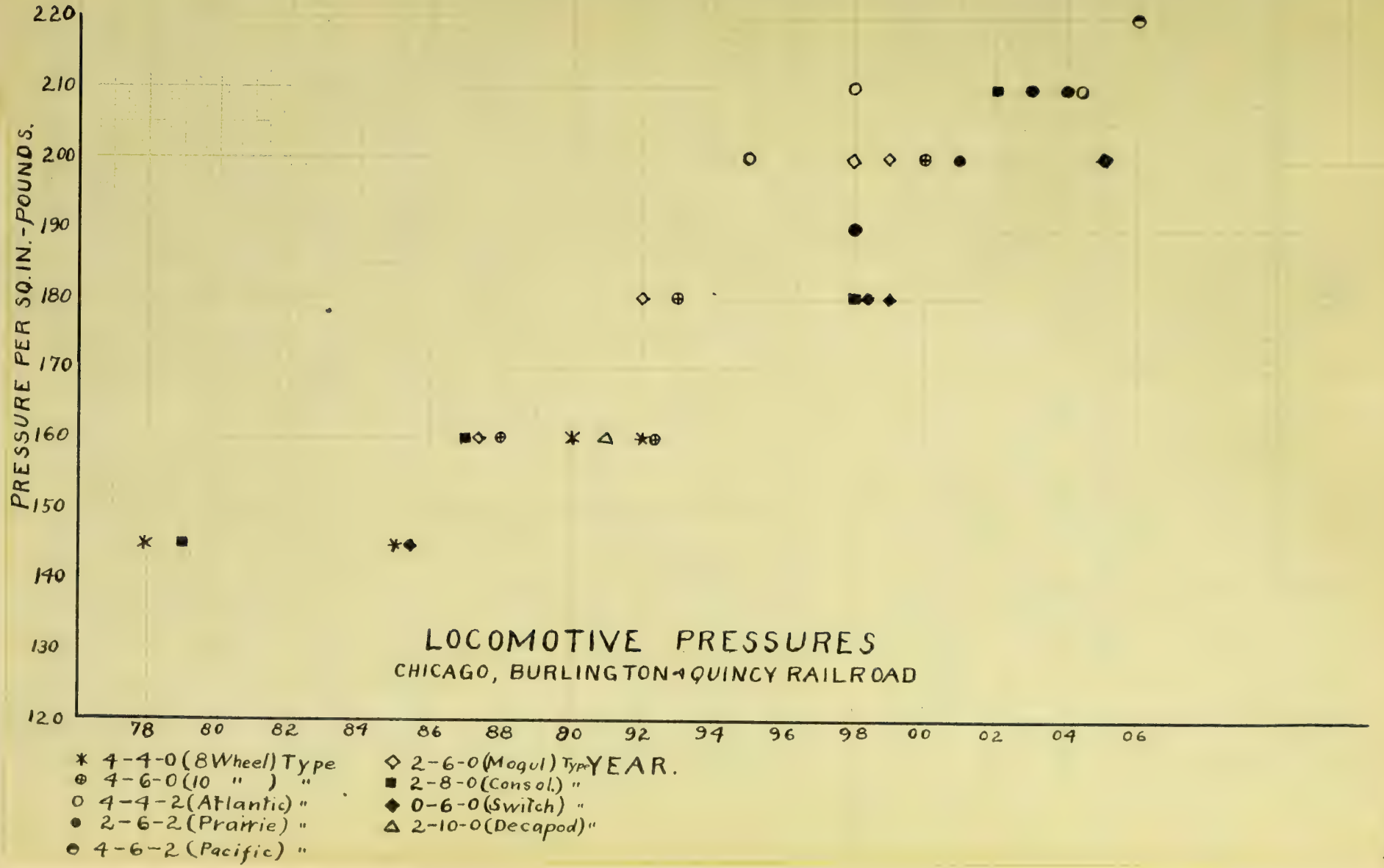
The heating surface of a locomotive boiler consists of the tubes, the crown sheet, the back tube sheet, the sides and back sheets of the firebox. The area of the front tube sheet is not taken into consideration in the heating surface of a boiler, since the gases are cooled so much before reaching the front end, that little heat is transmitted through this sheet. The heating surface of the fire box is much more effective than the tubes, while the heating surface of the tubes is much more effective in the back than in the front portion of the boiler. The heating surface of the boiler has increased with the size of the locomotive. This is shown by the plotted values on page 172-173 of the heating surface of 65 freight and

62 passenger locomotives built from 1895 to 1905. The grate areas are also shown on pages 174+175 for the same locomotives. Some of these locomotives are of the same type, but vary in weight and a few minor construct-ive features.

The largest locomotive boiler in use up to the present time is illustrated on page and has the following diamensions etc.:-

weight of boiler empty	84,000. pounds
" " " with water	117,000. "
heating surface	5,591. sq. ft.
grate area	72.25 " "
lenght over all	38'-5"
largest diameter	88 inches

Numerous plugs 2 to 2 1/4 inches in diameter are screwed into the sides and back of the outer firebox sheets, in order to admit of inspection and cleaning sediment and scale from the crown sheet. The stay bolts may also be inspected through them. A plug is, also, placed in the bottom of each corner of the water leg, to faciliate cleaning out the mud from the mud ring.


PRESSURE PER SQ. IN. - POUNDS.
220
210
200
190
180
170
160
150
140
130
120
78
80
82
84
86
88
90
92
94
96
98
00
02
04
06
YEAR.
LOCOMOTIVE PRESSURES
CHICAGO, BURLINGTON & QUINCY RAILROAD
* 4-4-0 (8 Wheel) Type
⊕ 4-6-0 (10 ") "
o 4-4-2 (Atlantic) "
● 2-6-2 (Prairie) "
● 4-6-2 (Pacific) "
◇ 2-6-0 (Mogul) Type
■ 2-8-0 (Consol.) "
◆ 0-6-0 (Switch) "
△ 2-10-0 (Decapod) "

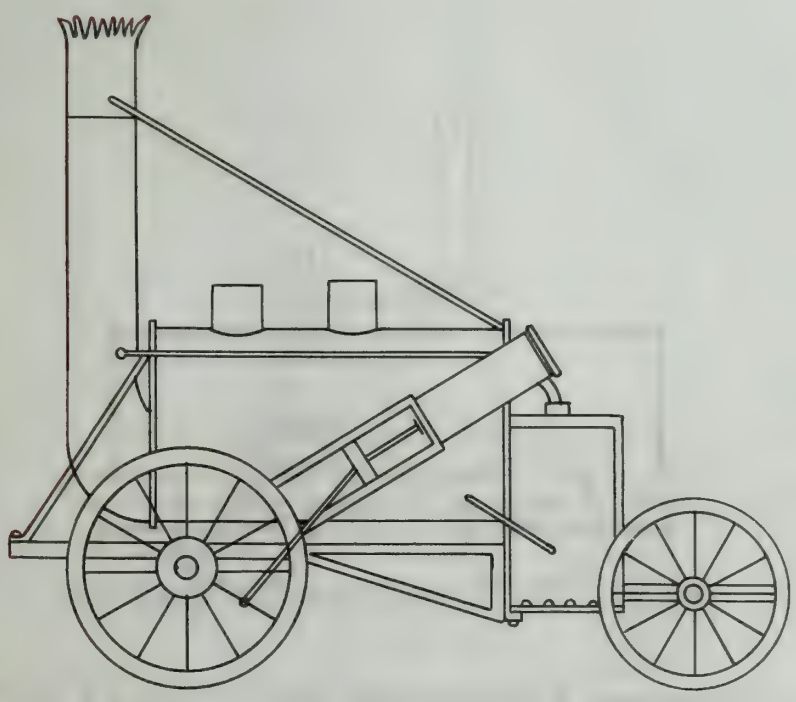
B.
Engine and Valve Gear.

1. History.

The early history and drawings of the locomotive shows that the cylinders with its attachments, including the valve gear, were small and crude in construction. The history of the locomotive gives the following table:—

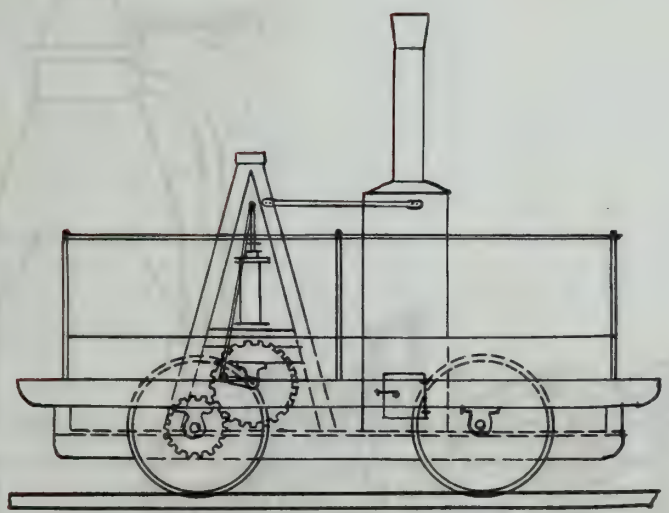
Name of Locomotive	Year Made	Number of Cylinders	Cylinder Dia. x Stroke	Method of Connecting to Drivers.	Drawing on Page.
Rocket	1829	2	—	Outside Crank	66
Tom Thumb	1830	1	$3\frac{1}{4}$" x $14\frac{1}{4}$"	Geared	67
Best Friend	"	2	6" x 16"	Inside "	68
West Point	1831	2	6" x 16"	" "	69
De Witt Clinton	"	2	$5\frac{1}{2}$" x 16"	" "	70

This table shows that the cylinders were of small diameter, while the proportion between the lenght and diameter was greater than in modern construction. The slide valves used were worked by a single eccentric rod; and in reversing engine, had to be changed

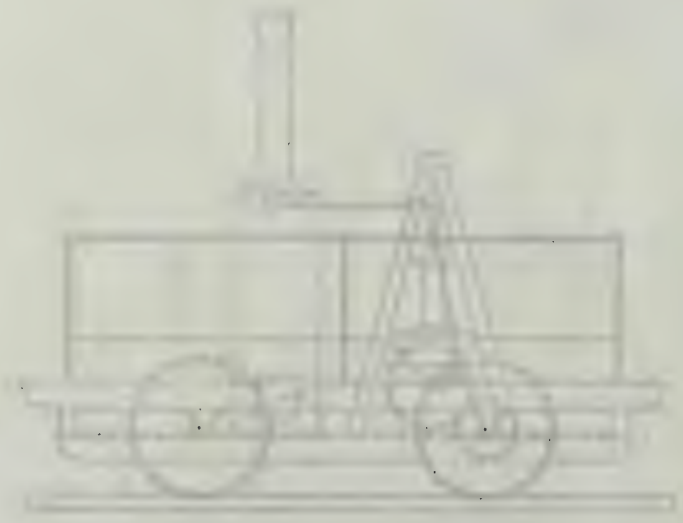


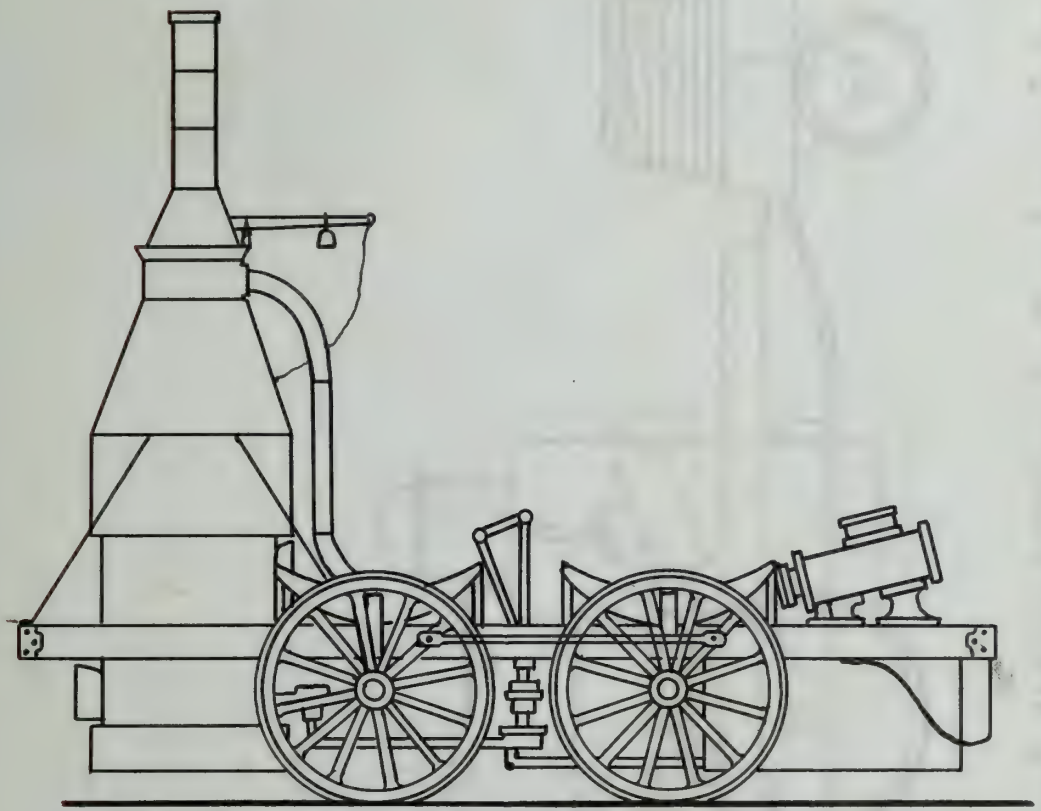
THE ROCKET

STEPHENSON'S ENGINE

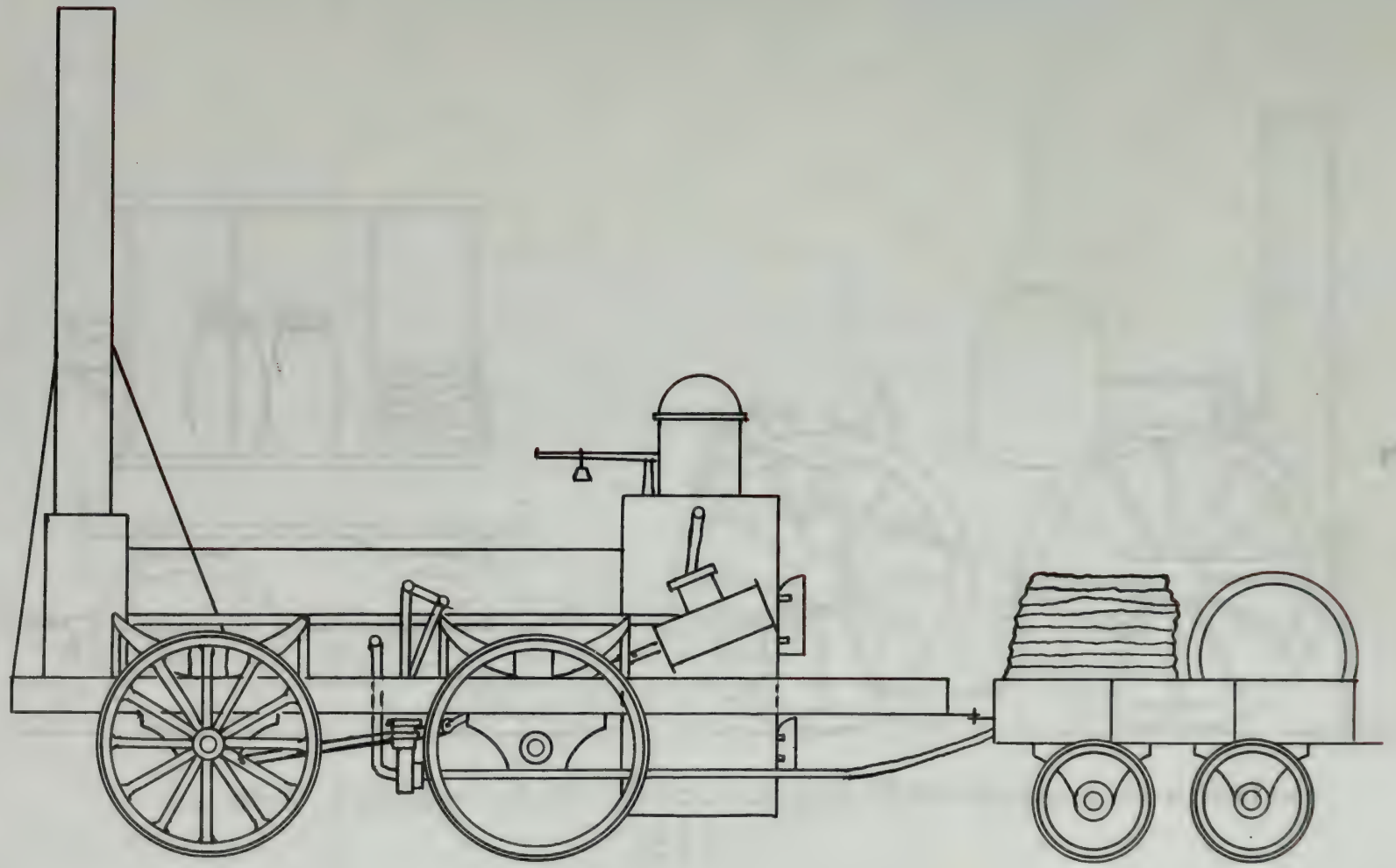


"Tom Thumb" 1st. American Locomotive.
1830



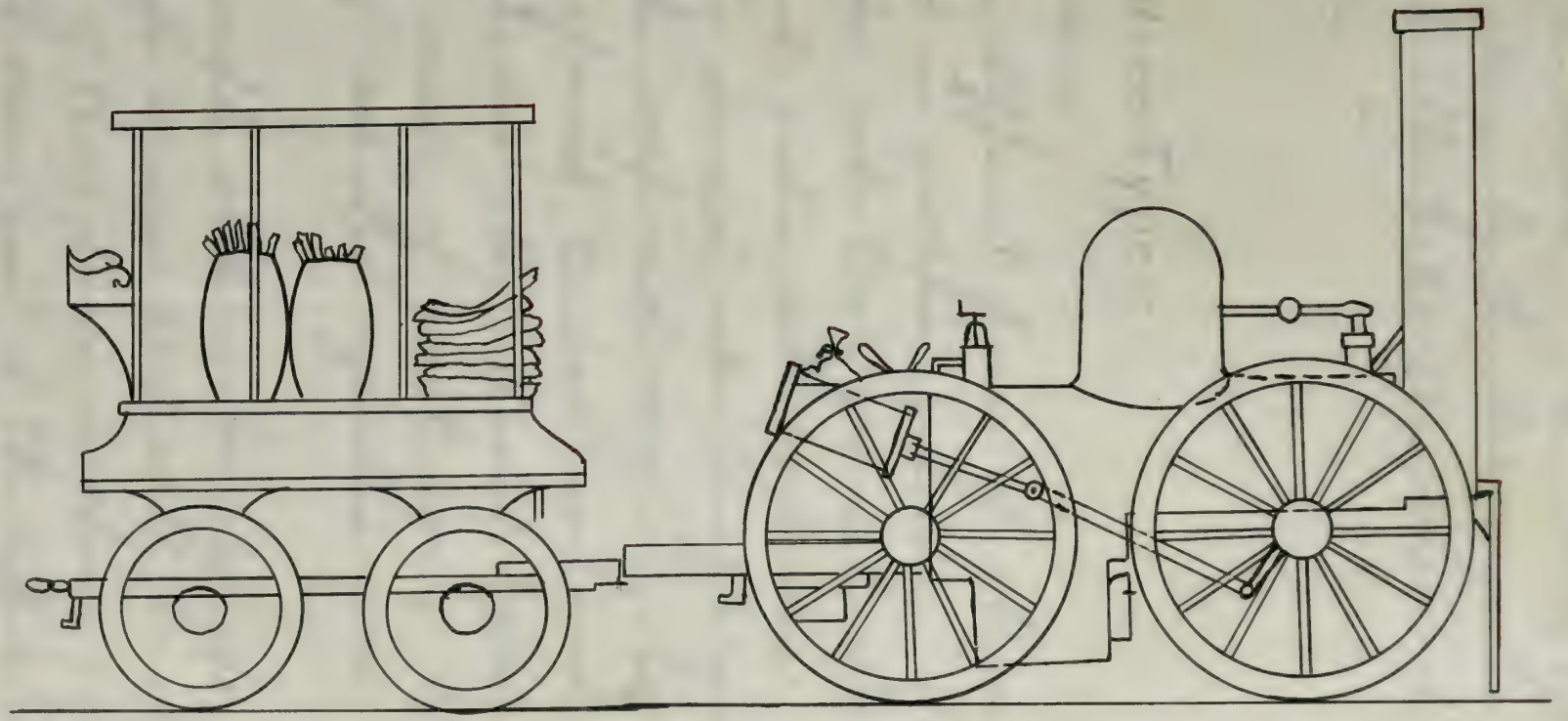


"The Best Friend" 1st Successful American Loc-
-omotive 1830.

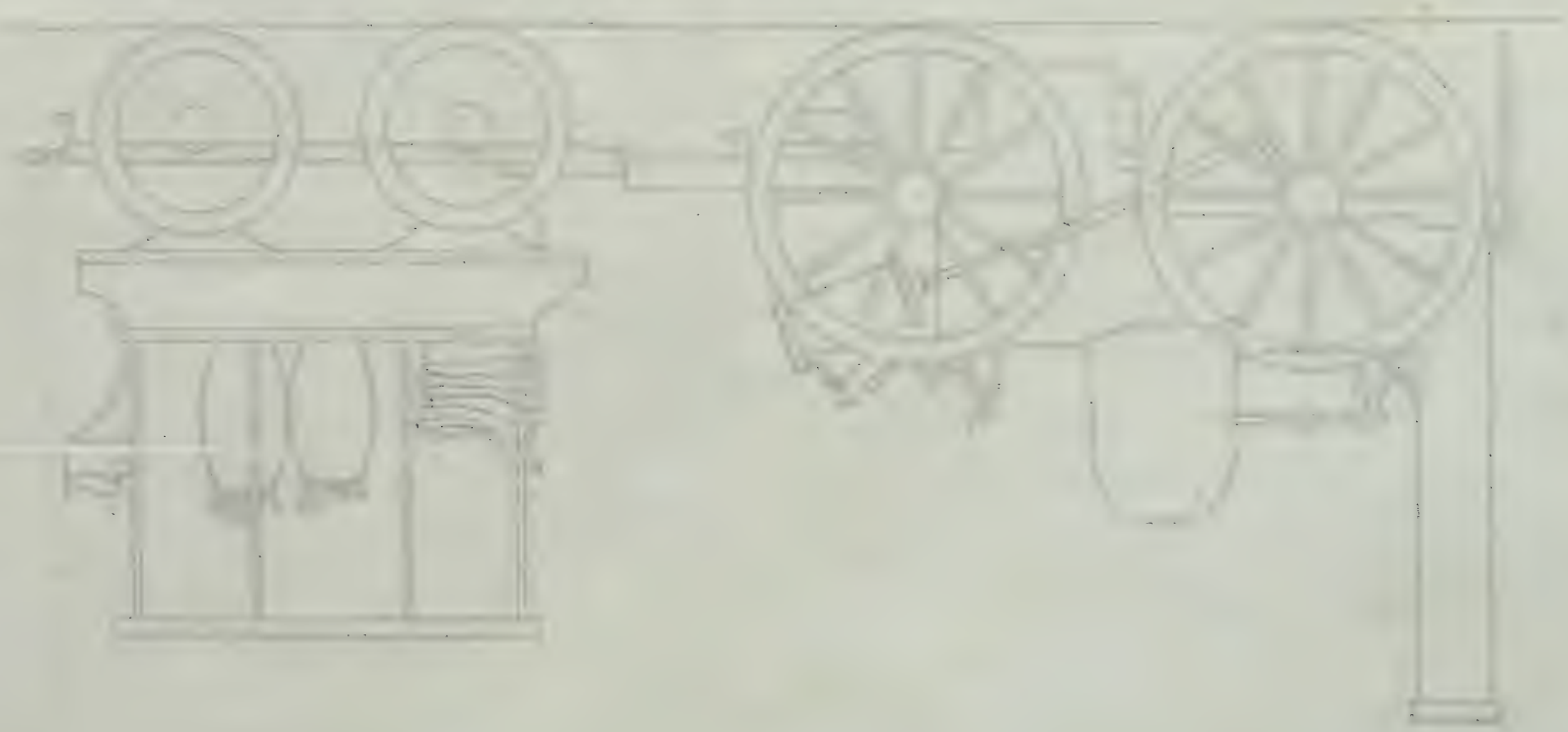


"The West Point 2nd Locomotive Built in the U.S. for Service.

The Westfort Self-propelled Drill in the U.S. Patent Office.



"DeWitt Clinton" 3rd Successful American Locomotive.
1831



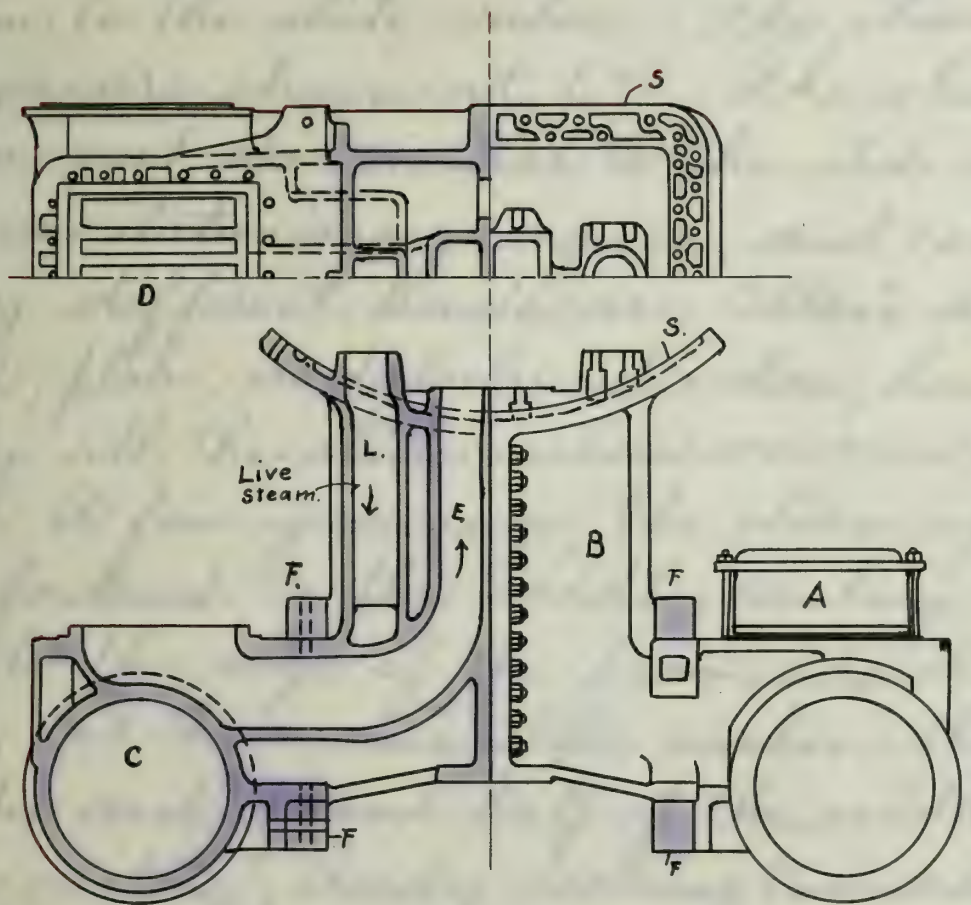
or hooked on another pin, while the locomotive was not in motion. The earlier types of locomotives are shown by the drawings on pages 66 to 70, which illustrates the constructive features of each.

2. Madern Types:-

a. Cylinders.

Many different forms of steam cylinders are used in modern practice. These may be divided into two general classes: slide valve, and piston valve cylinders. These may again be divided into simple and compound, while the compound may be divided into:- cross compound, tandem compound, Vauclain compound, and other special types. They are all made of cast iron. Recently, however, a pair of cast steel cylinders were successfully made.

The simple slide valve cylinder is the oldest type in use and will be described first. A sketch of the cylinder is shown on page 72. Above the main part of the cylinder is the steam chest (A), which is bolted to the main cylinder casting B; copper wire being used as



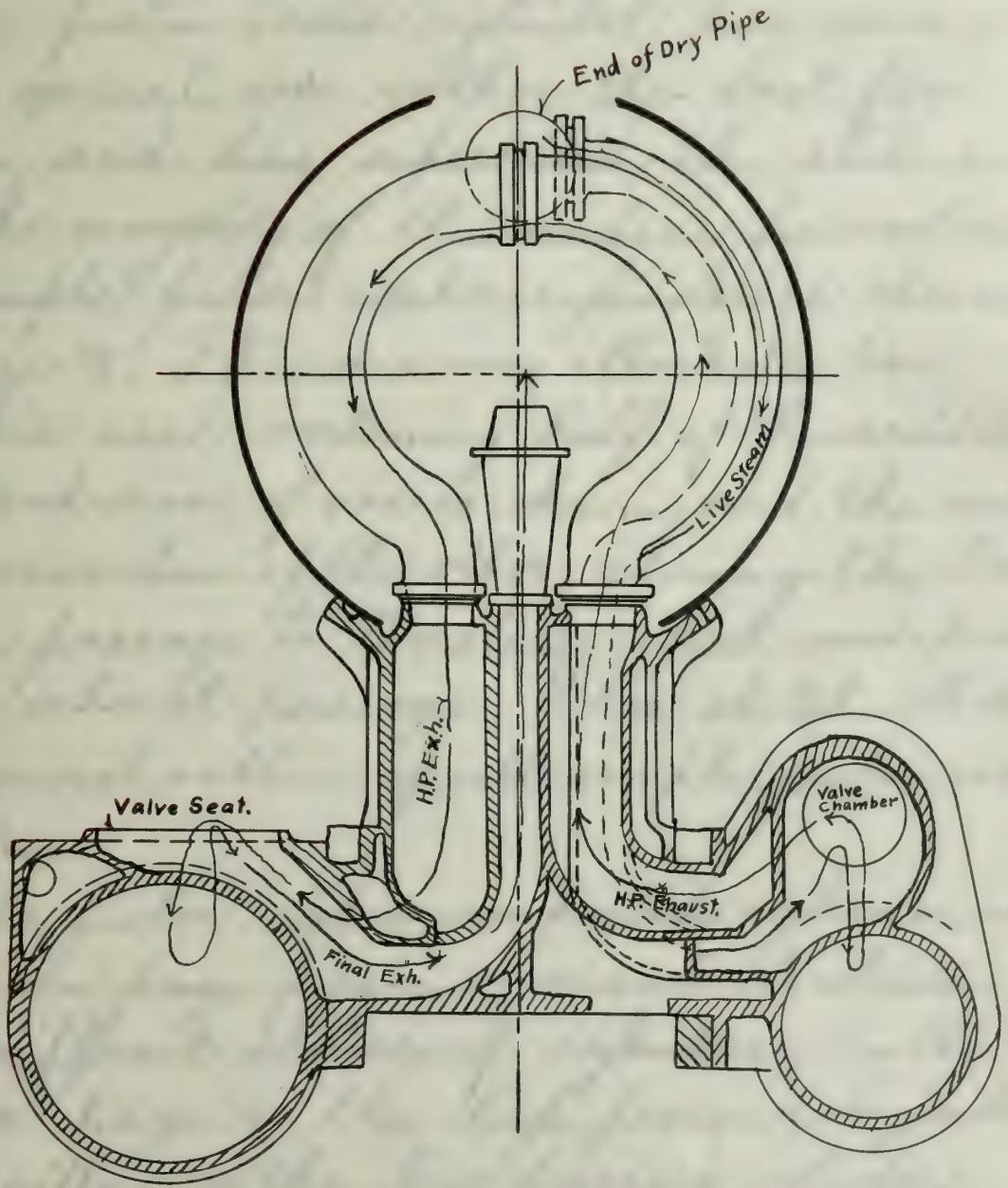
SLIDE VALVE CYLINDER.

SLIDE VALVE CYLINDER.

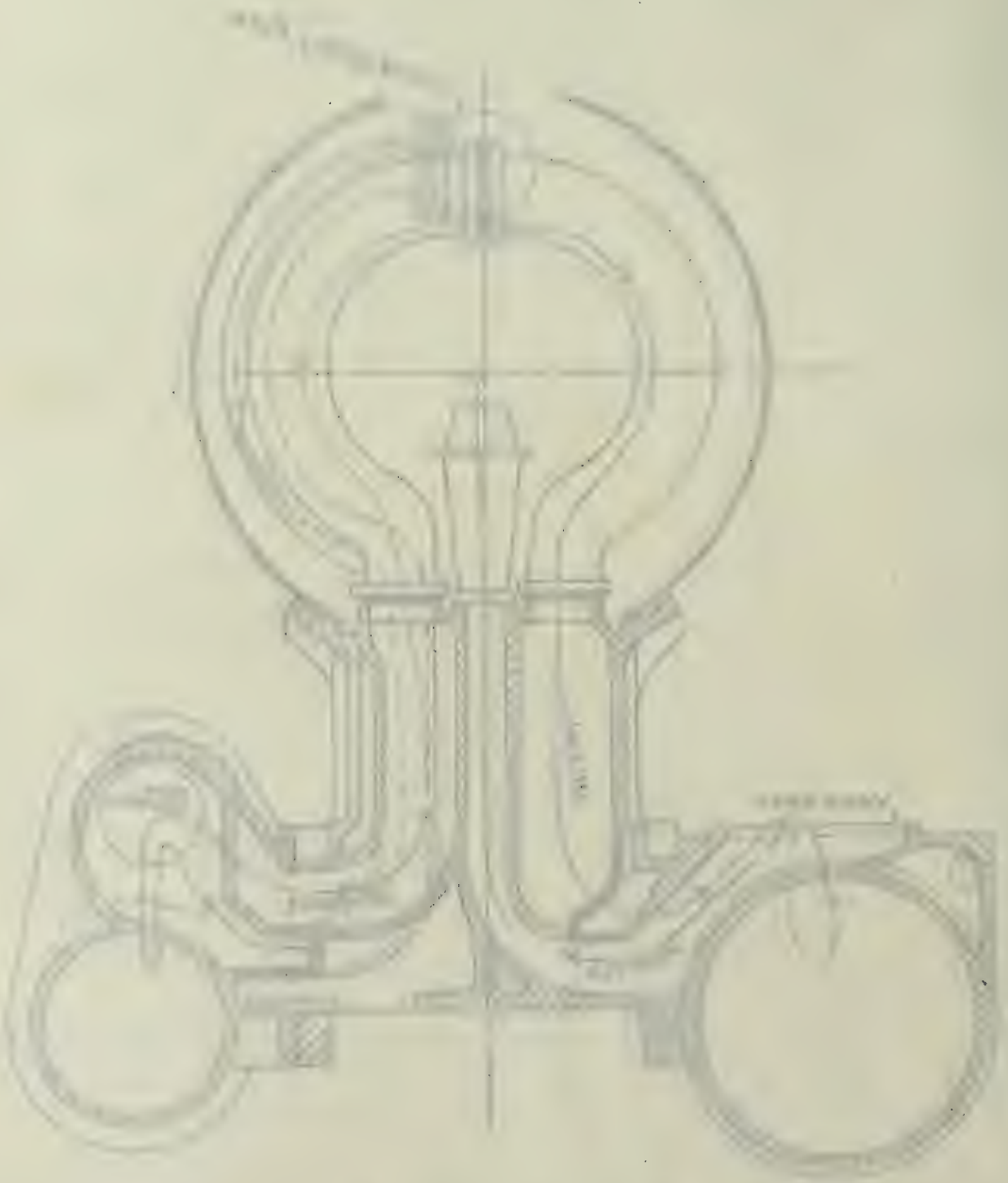
packing to make a steam tight joint between the castings. This steam chest has a cover, and a stem, working through a packing gland on the end of this chest, transmits the motion to the slide valve. The steam passages are shown at E & L. The slide valves used are similiar to the slide valves used on stationionary engines, and comprises many different kinds, as: Allan's double ported, plain, and balanced valves, however, nearly all the slide valves are now balanced. A few years ago, the steam cylinders were fastened to the saddle casting, which came to the edge of the frame as shown at F, but the modern style makes the cylinder casting and half of the saddle S in one casting; thereby making two castings in place of three, and doing away with the troublesome steam tight joints between the cylinder casting and sadde casting. In former practice a few years ago these joints gave much trouble; as a little jar on the cylinders would cause a leak. This has now been done away with, by making the cylinder and half of the saddle in one casting.

The cylinders of this form as well as all the modern ones are placed at the head of the locomotive, and outside of the frames as shown at F. There are a few exceptions to this, however, for one set of the cylinders of a balanced compound locomotive are placed inside of the frames as shown on page 145, while the drawing on page 165 shows the high pressure cylinders of the Mallet compound placed midway between the ends of the locomotive.

The slide valve cylinders are made in either the compound or simple engines. Again they may be made in cross compound or tandem compound. If they are made cross compound, they are connected as shown on page 75, which shows a Mellin, or Richmond cross compound locomotive having two cylinders; one high pressure and one low pressure. One of the cylinders is operated by a piston valve, and the other by a slide valve; however, they may be both slide or piston valve in the cross compound. The slide valve cylinder may, also, be used as a tandem compound as in stationary practice. Not many locomotives are built



Mellin Cross Compound.

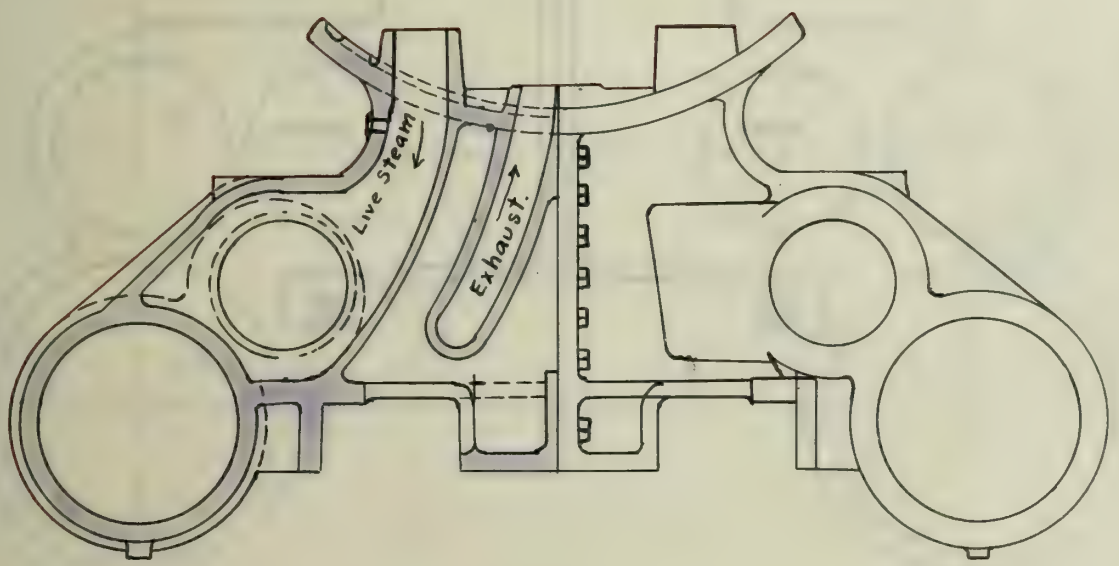


thus, and they will not be described here, as their construction is similar to those used in stationary practice, with the exception that they are made for the locomotive.

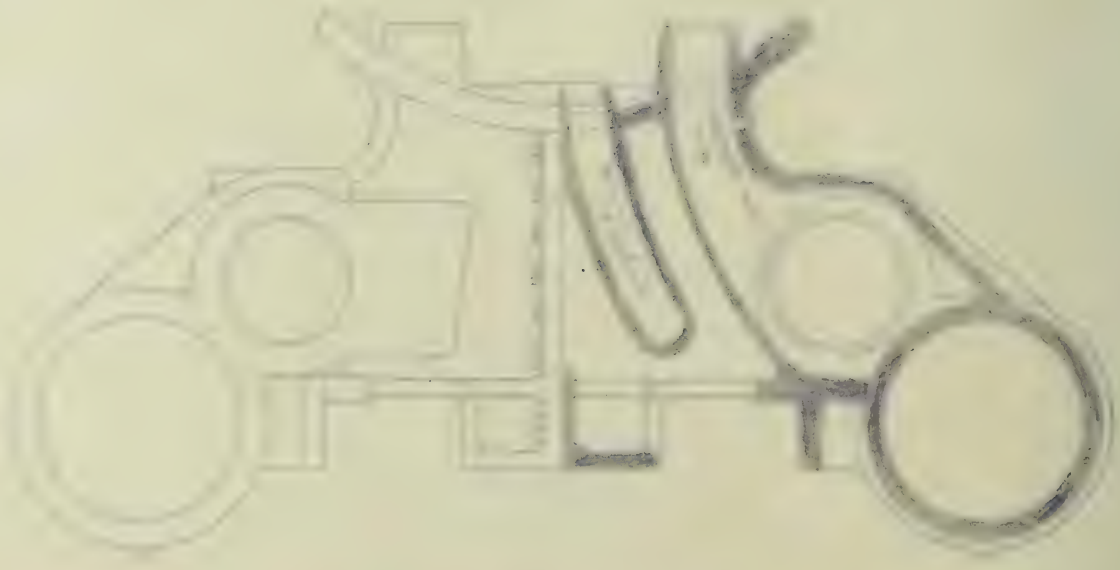
The piston valve cylinder has come into quite general use within the last few years, and has superseded the slide valve on the majority of the modern locomotives.

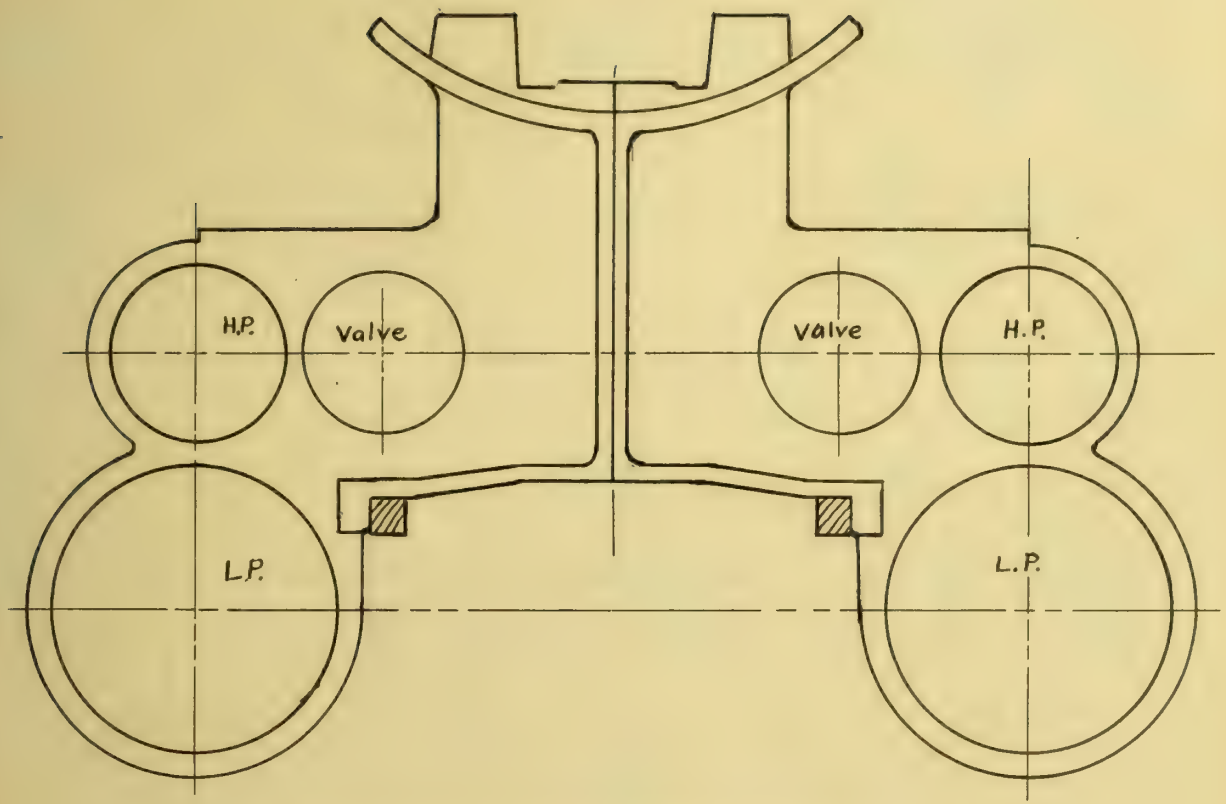
A simple piston valve cylinder is shown on page 77. This drawing illustrates two cylinders each containing half of the saddle. The end view of one is shown, and the central crossection of the other, showing the live steam passage to the steam chest and part of the exhaust passage. This sketch illustrates the general outline of all simple piston valve cylinders.

The piston valve compound cylinder is shown on ~~page~~ pages 78 & 145 and illustrates two different classes of cylinders. In the one on page 78, the high pressure cylinder is directly over the low pressure cylinder; however, it is sometimes made with the low pressure above the high pressure cylinder, but the former method is the usual construction. This type of cylinder



SIMPLE PISTON VALVE CYLINDERS.





Vauclain Compound Cylinders.

with its piston valve is called the Vauclain compound type.

The Vauclain balanced compound cylinder as used on the balanced compound locomotive is shown on page 145, which shows the general outlines of the cylinders. The pistons are connected to seperate cross heads, which in turn are connected to different sets of drivers, or they are sometimes connected to the same pair of drivers. The crankpins are placed at an angle of 180° with each other for the same pair of cylinders, thus balancing the reciprocating parts by similar horizontal moving parts.

The advantageous features of the four cylinder balanced compound are:-

(a) Balancing of reciprocating parts by similar horizontal moving parts. One outside piston and its attachments moving forward while the inside piston is moving backward. These nearly balance each other without the use of unbalanced weights in the wheels.

(b) The increase of weight permissable on the driving wheels when considered dynamically. In the ordinary locomotive, at sixty miles

an hour, with 78" drivers, the increase or decrease at each revolution of the static weight on the rail is about 23%, which is due to the centrifugal effect of the excess weights used to balance the reciprocating parts.

(c) Dividing the power on two axles and four cylinders, thereby reducing the bending stresses on the crank axle due to the fact that only half of the turning moment is transmitted through each axle.

(d) Simplicity in design. One set of valve gear with comparatively few parts when compared with foreign designs.

The figure on page 75 shows a type of cylinders used on the Mellin, or Richmond compound locomotive. As illustrated, the high pressure cylinder is operated by a piston valve, and the low pressure by a slide valve. The steam passages are shown, from which the the steam can be traced by means of the arrows. The exhaust steam from the high pressure cylinder is passed through the steam pipes, in the front end as shown, where it receives heat from the heated gases of the front end.

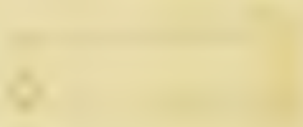
A few other types than those mentioned above

are used, but the above cylinders comprise the majority of the cylinders used in modern construction.

b. Pistons + Packing.

Pistons are generally made of cast iron or steel. The majority of them are made of cast iron. Page 82 shows the various types of pistons in use. They may be made either solid or hollow, depending on material and the size and form. The pistons in the high pressure cylinders of a compound locomotive are sometimes made solid and of cast iron as shown in fig. 1, or they may be made hollow as in fig. 2. The low pressure piston of a compound must be made strong enough to withstand the boiler pressure carried, since in using the starting valve, the pressure in boiler is used without compounding. The pistons are not made to rub against the cylinder walls, but the packing must wear against the cylinder walls and make a steam tight joint.

The piston packing consists of cast iron rings held in place by a flat spring which presses



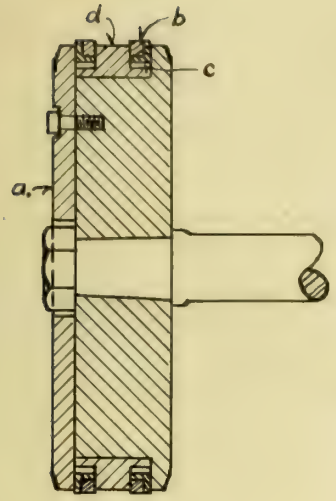


Fig. 1.
Old Style C.I. Piston

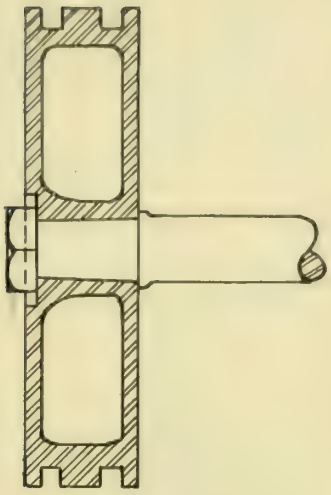


Fig. 2.
New Style C.S. Piston

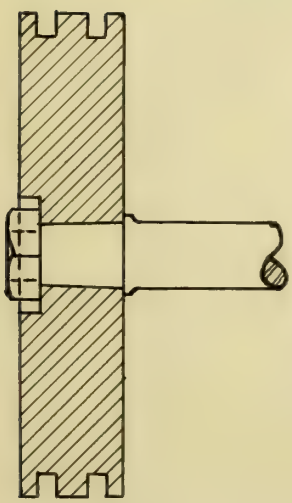


Fig. 3.
New Style C.I. Piston

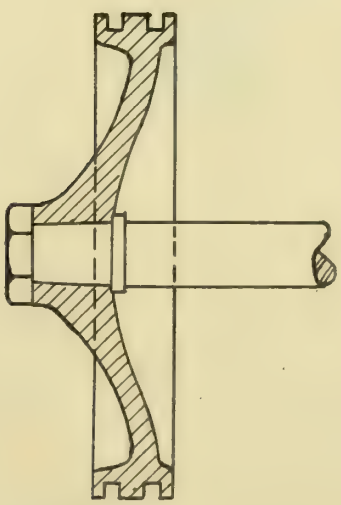


Fig. 4.
New Style C.I. or C.S. Piston

the packing to the cylinder walls. Modern piston packing consists of the following: a single cast iron ring is used of the following cross section

, or the most modern packing consists of two cast iron rings in the shape as shown in the following figure. This latter packing is cut in sections, and the strips are made to lap joints, so as to not let steam leak through.

Fig. 1 on page illustrates an old type of piston with the packing in place. This piston has what is called a follower plate a. The ring d is to be taken from the piston in putting or taking packing rings in the cylinder. The packing is shown at b, and c is the spring to hold it in place against the cylinder walls.

The pistons are generally fitted to the rod as shown, but some are screwed onto the piston rod.

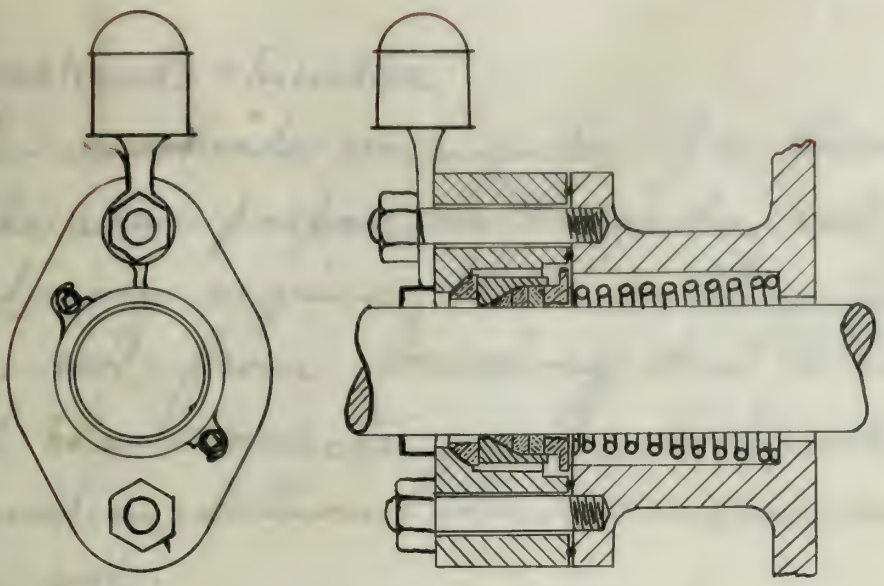
The piston shown in fig. 4. is of peculiar shape, and is made so as to give it greater strenght for the same weight of material. This style of piston may be made of cast iron

or steel, depending upon the size and pressure used. The cylinder heads used with a piston of this shape, must conform in shape to the piston, so as to not have too great a clearance space.

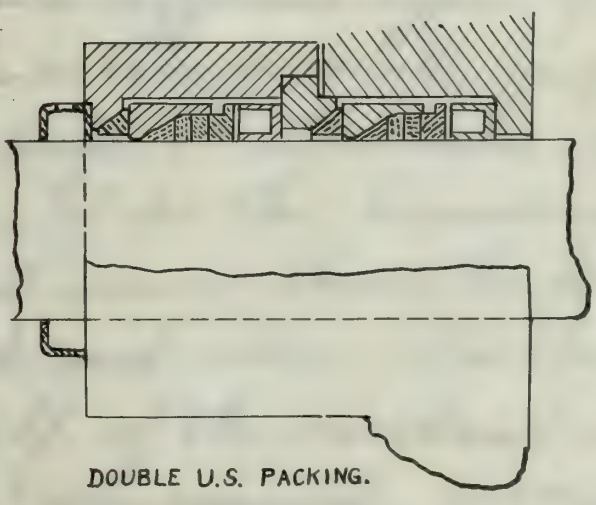
b1. Piston Rod & Packing.

The piston rod packing must be steam tight and contain the least amount of friction on the rod. This is impossible to get, as the rod packing will always leak somewhat. The various kinds of packing used are illustrated on page 85. Metalic packing is used extensively in locomotive practice. The construction of the various kinds, is readily understood from the drawings. The metal that comes in contact with the piston rod is made of soft babbit rings which are held in place as shown by the springs and other mechanism.

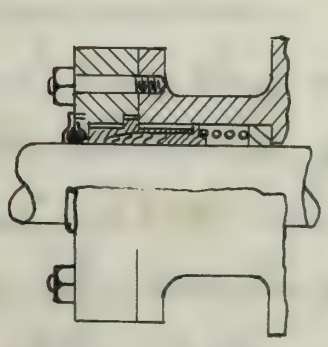
Extended piston rods are now used quite extensively on some heavy locomotives. The purpose of which is to carry the weight off from the bottom of the cylinder. The are fairly good for this purpose, but the extra work in its construction is against ~~it use~~ extensive use.



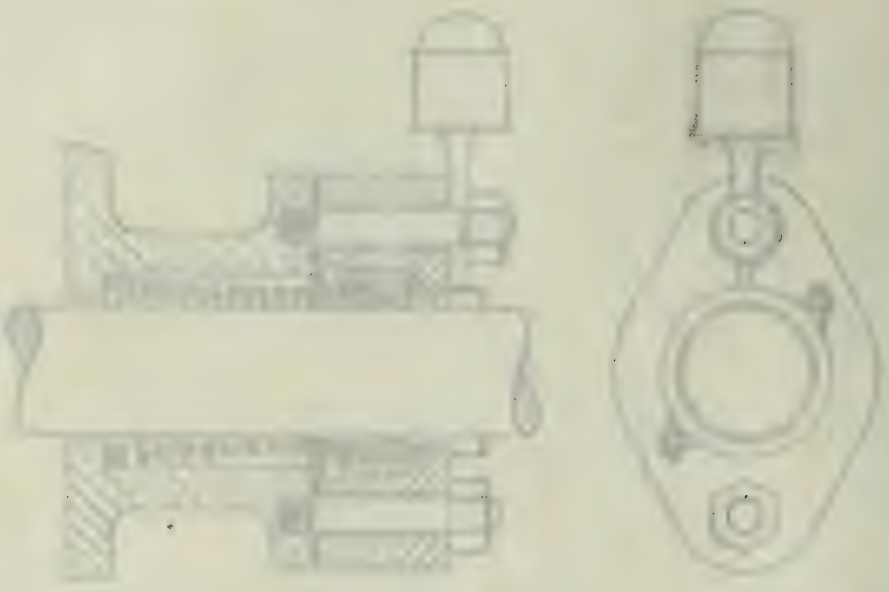
UNITED STATES PISTON ROD PACKING.



DOUBLE U.S. PACKING.



THE JEROME METALLIC PACKING.



C. Crossheads & Guides.

The crossheads and guides of a locomotive serve the same purpose as the guides and crosshead of stationary engines, that is; they keep the piston rod from bending due to the angularity of the connecting rod, and serve as a connection between the main rod and the piston rod.

There are five different types of crosshead and guide arrangements in general use. Fig. 1 on page 89 illustrates a type sometimes spoken of as the locomotive crosshead; the different views show the plan, side elevation and end view. In the side elevation one half of the crosshead and two of the guides are removed, so as to show the main rod connection.

The main crosshead casting is made of cast iron or steel. As shown in fig. 1, this casting is made solid, and contains the wrist pin; in this case, the casting is made of cast steel. In the other types of crossheads shown, which are made up in parts; the material employed may be cast iron, steel or wrought iron. The body is generally made

of cast steel for lightness, and the sides or shoes are made of cast iron. The shoes are generally babbited, or contain brass liners for the wearing surface next to the guides.

The piston rod is fitted to the cross-head by a taper socket, a taper key holding the rod in place; or as in the compound type of crosshead, by a nut on the end of the piston rod as shown in figure 5.

The front end of the guides are bolted to the back cylinder head, while the back ends are secured to the guide yoke as shown in fig. 1, and which is bolted to the engine frame.

The guides are set parallel to the center line of the cylinder, both horizontally and vertically; so that the crosshead must move in a straight line parrallel with the axis of the cylinder, to avoid bending the piston rod.

The crosshead illustrated in fig. 1 is and old style and can be seen on many old locomotives in use today. The cross head in figure 2 has only two guides, one above and one below the crosshead. This style of crosshead is used to a great extent on modern heavy locomotives. The crosshead in fig. 3 has two

guides also, but in this type both guides are above the wrist pin. This type is used to a great extent on the lighter class of locomotives. The crosshead in fig. 4 has only one guide. This type of crosshead is not used extensively. Fig. 5 illustrates the crosshead with four guides and having two piston rods, one above and one below the guides. This type is used on the Vauclain Compound locomotives, where one cylinder is vertically above the other. These illustrations show the construction of the crossheads clearly, so that no further discriptions are neccessary.

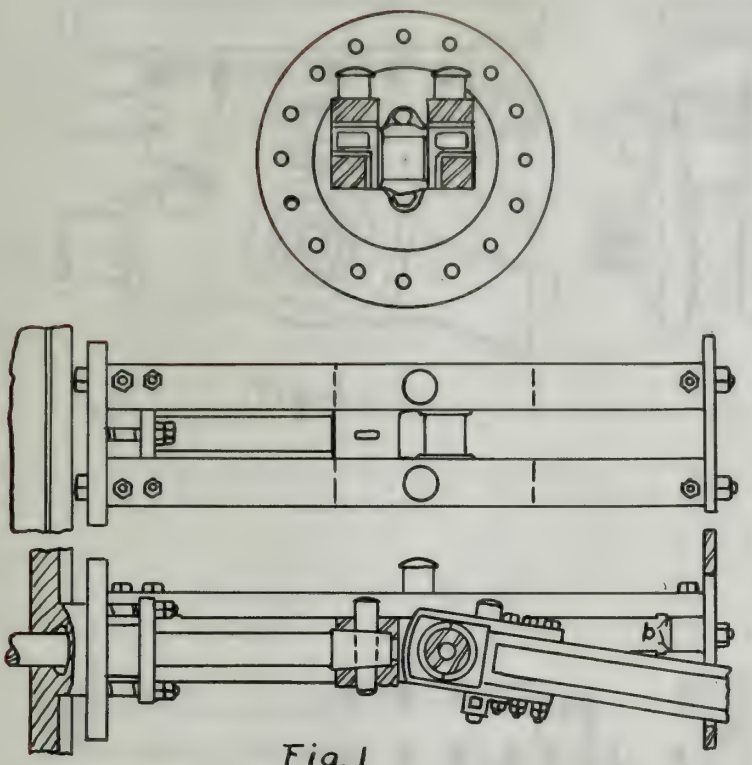


Fig. 1.

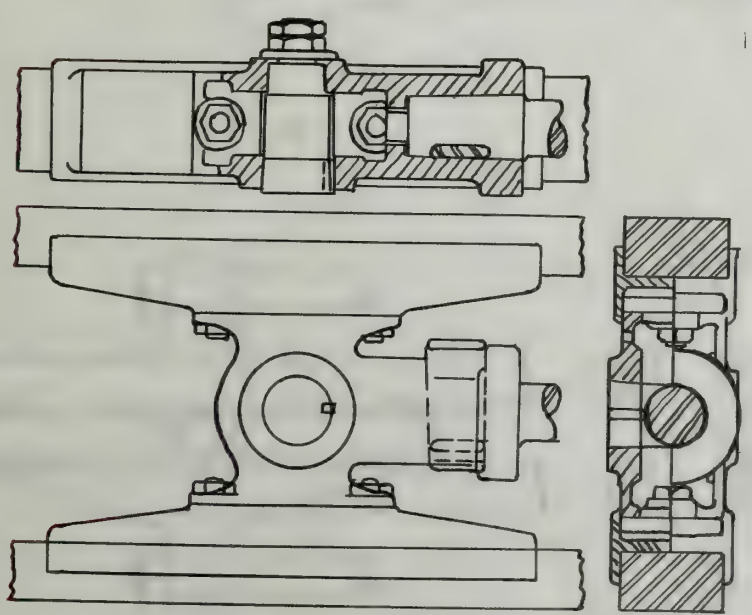
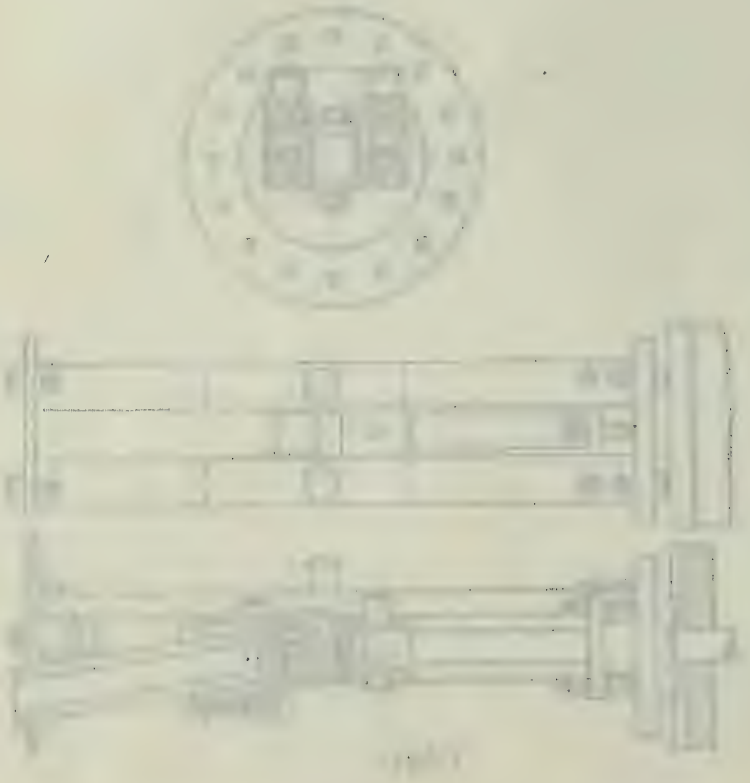


Fig. 2.



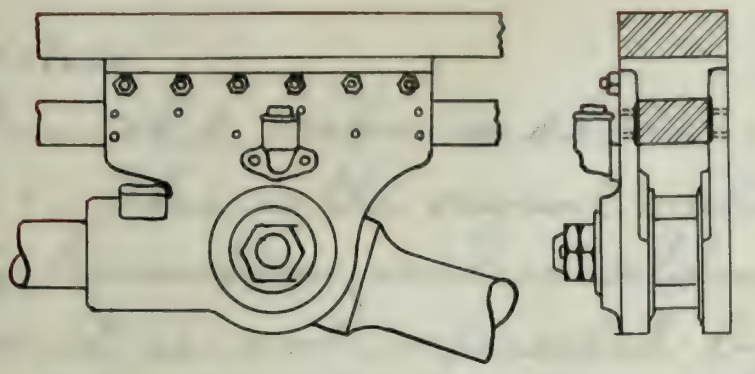


Fig. 3.

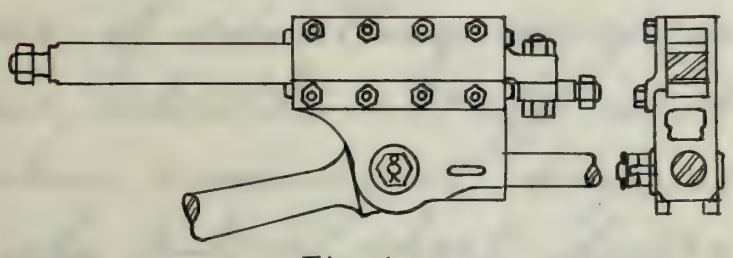


Fig. 4.

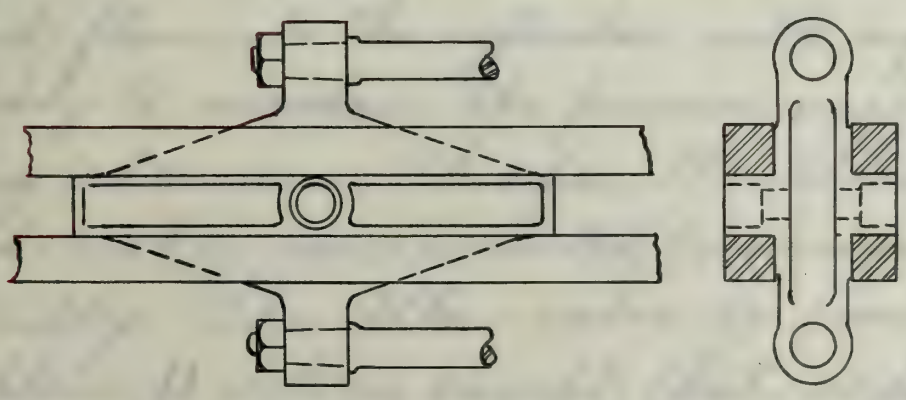
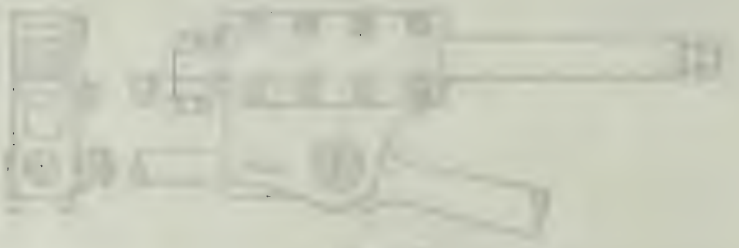
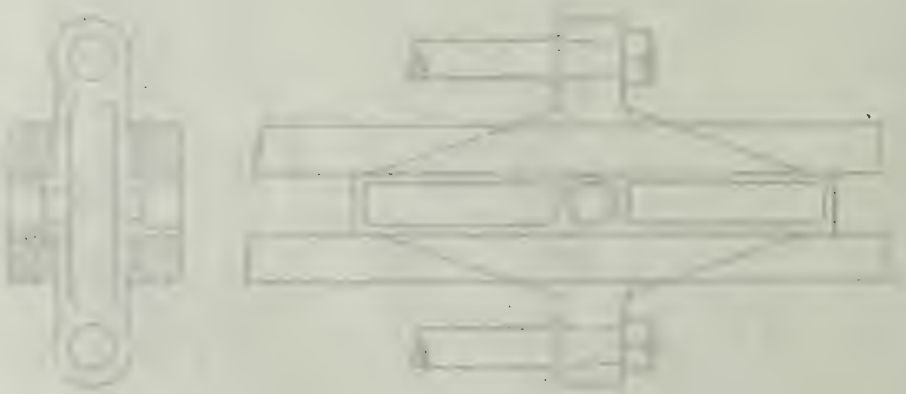


Fig. 5.





d. Valves:-

1. Slide Valves.

The plain slide valve is shown on page 93 in fig. 1. This is the original valve used on the early locomotives, and is seldom used today, since it is now superseded by the balanced type of slide valves which give much less resistence to the motion of the valve.

The valve shown in fig. 2-3 is the Allen double ported valve. This was designed to overcome of admitting enough steam to the cylinders, when the cut-off is short, as is the case when running at high speed. The valve travels but a short distance at short cut-offs, consequently the valve opens the port such a small distance that steam cannot flow into the cylinder with sufficient rapidity to mantain the pressure nearly constant during admission. Therefore, the Allen double ported valve was invented to overcome this difficulty. The Allen valve is similar to the plain D valve, except that a passage allows the steam to enter at more than the regular place as in the plain valve. The valve in fig. 2 is used on the low pressure

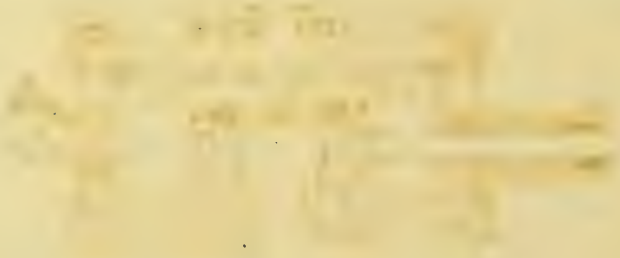
cylinder of a Richmond or Mellin compound locomotive, in order to have as low a back pressure as posible without the use of large valves.

The Allen double ported valves are used extensively in locomotives, but are nearly all of the balanced type, which are next described.

Fig. 4 illustrates the Richardson balanced valve. Other types of slide valves are balanced in a similar manner. The strips a and b are the packing pieces, while c c are springs to press them against the balance plate P. The hole e is to equalize the pressure of the exhaust on the under side of the valve, by allowing the pressure on both sides to be equal.

The above figure also shows the Richardson relief valve as applied to the steam chest, to prevent a vacumm in the cylinders, when running with the steam shut off.

There are various other forms of balanced valves in use, but the principle by which they work are similar to the above, so they will not be described here.



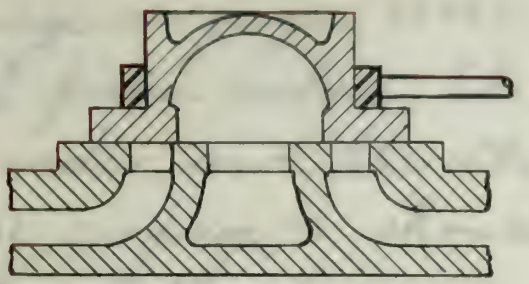


Fig. 1.
PLAIN SLIDE VALVE.

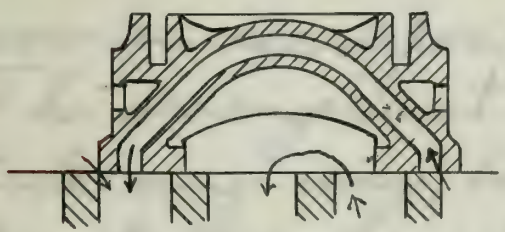


Fig. 2.
Allen Double Ported Valve.

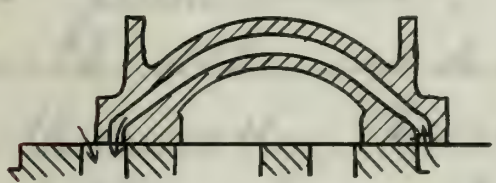


Fig. 3.
Allen Double Ported Valve.

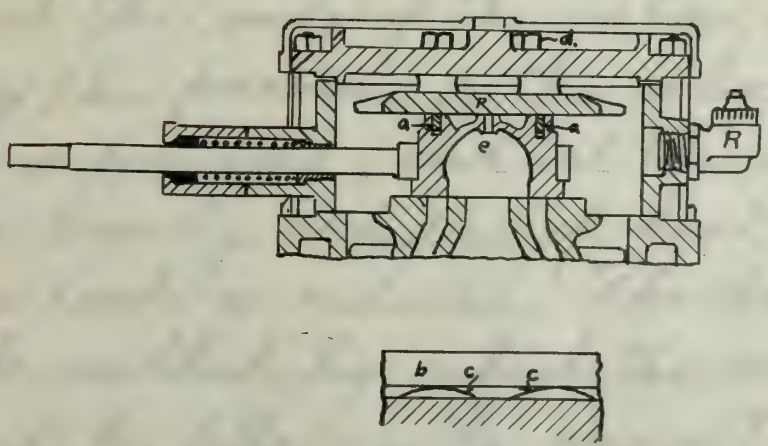
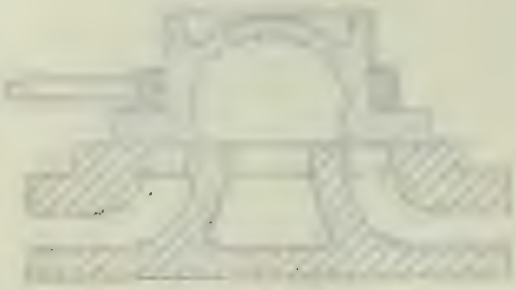
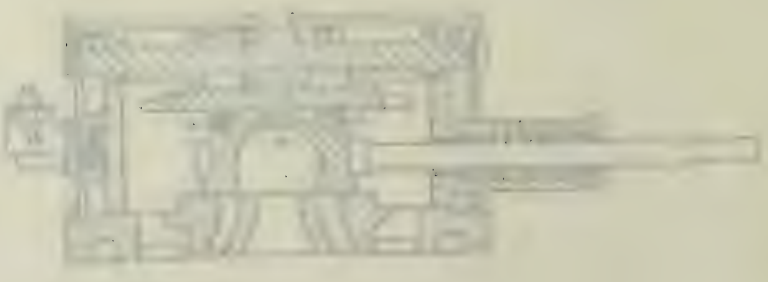
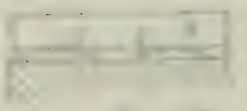


Fig. 4.
Balanced Valve.







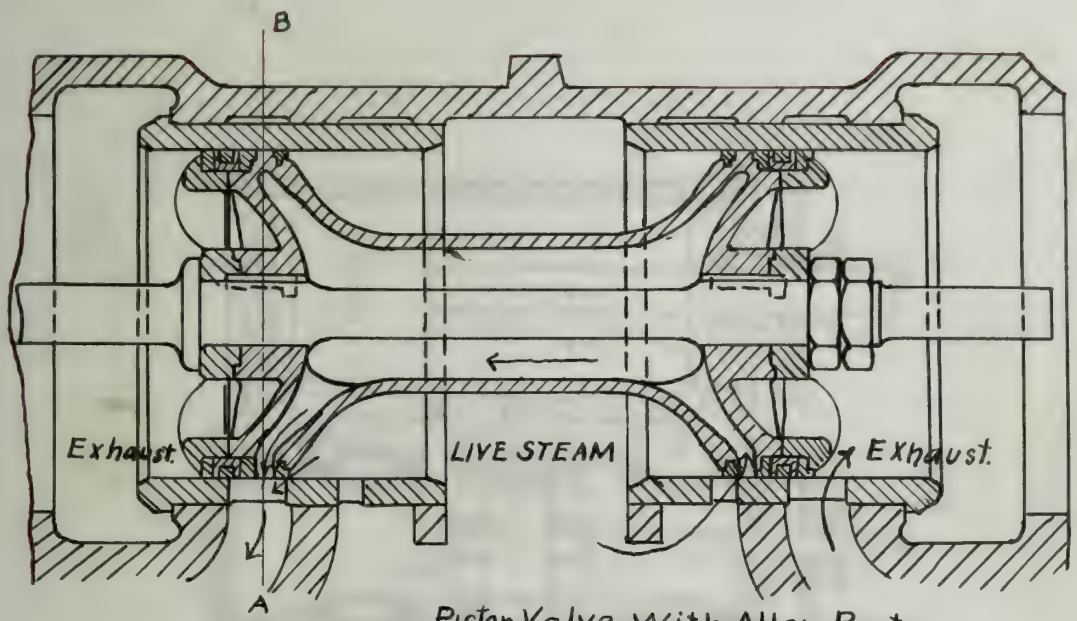
2. Piston Valves.

The drawings on pages 96-97 shows two different types of piston valves; the one is used for compounds, and the other for simple engines. The one on page 96 shows a piston valve with Allen ports, however, without this feature, it would be similar to many piston valves now in use upon many locomotives. The arrangement of ports and other details may vary, but the general constructive features are the same for the various piston valves. This valve may be made with either inside or outside admission; or in other words, the exhaust may be either at the ends or at the middle of the valve. The exhaust is generally placed at the ends of the valve; since by so doing, the pressure on the valve steam packing is decreased, and at the same time the loss by radiation of heat through the valve heads is reduced. The drawings shows the method by which the valves work, and by following the arrows the steam can be traced in its path through the cylinder.

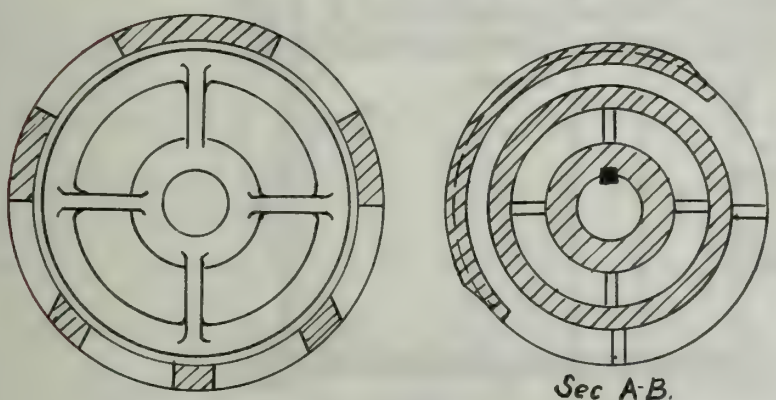
The drawing on page 97 shows the piston valve used on the "Balanced compound", having the high pressure pistons between the frames as shown on page . With a little different arrangement of piston and ports, this valve is similar to those used on other compounds. The other piston valves in use are similar in construction, so will not be described here.

From the two drawings of piston valves, it is easily seen that the valve chamber consists of an irregular circular space, into which are fitted two bushings having the port holes in their walls. This is made thus, so as to be able to make the ports accurate, which could not be done if they were cast with the cylinder casting. These bushings also serve as an easy means of repairing worn out piston valve bushings or chambers. The valve itself is cylindrical in form and contains cast iron packing rings. The advantage of the piston valve over the slide valve are:-

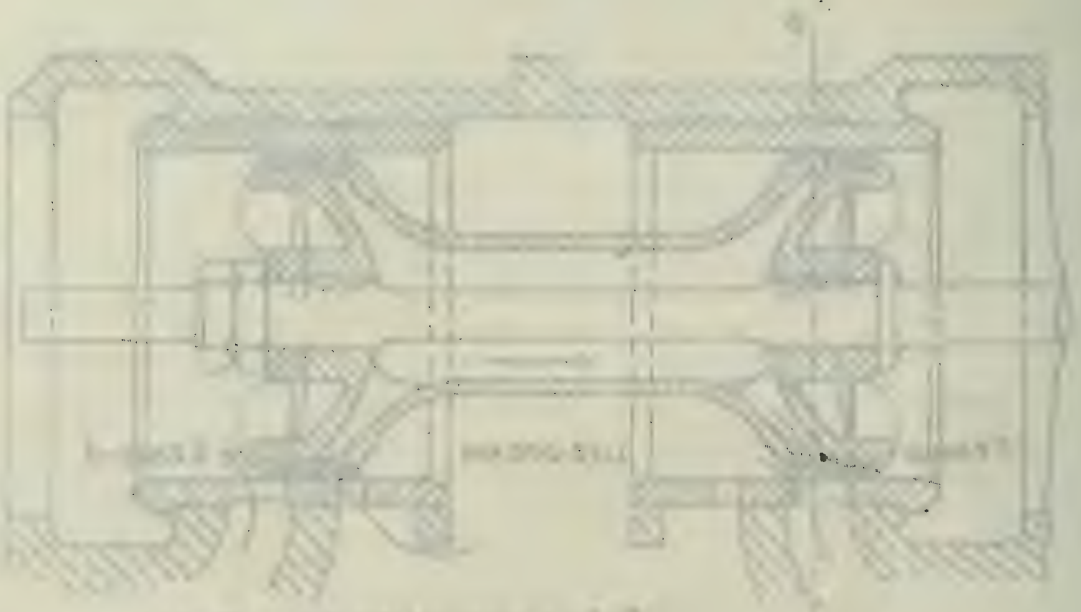
Gives greater port opening for the same move-

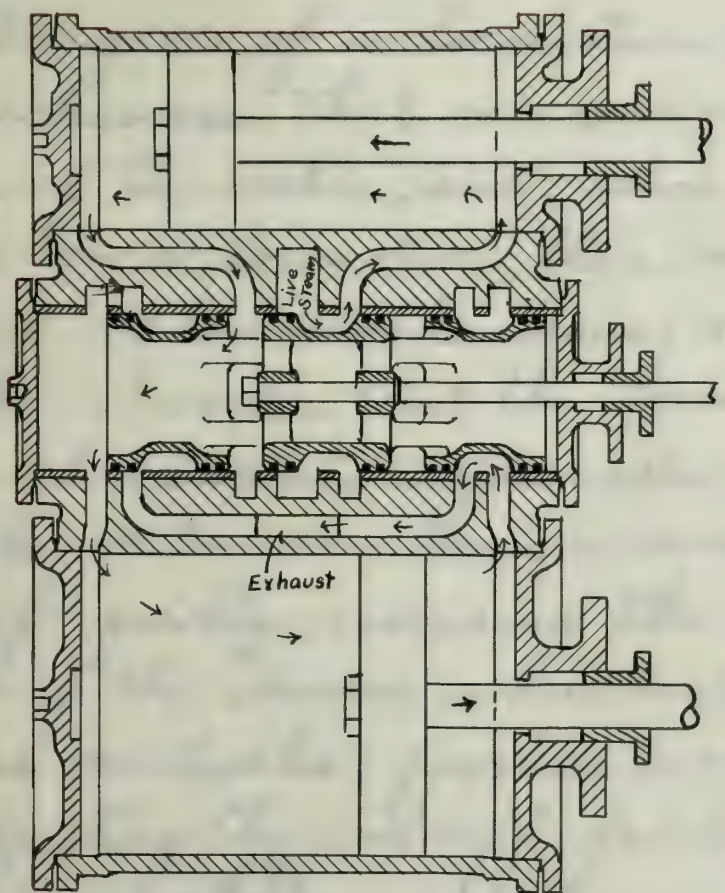


Piston Valve With Allen Ports.

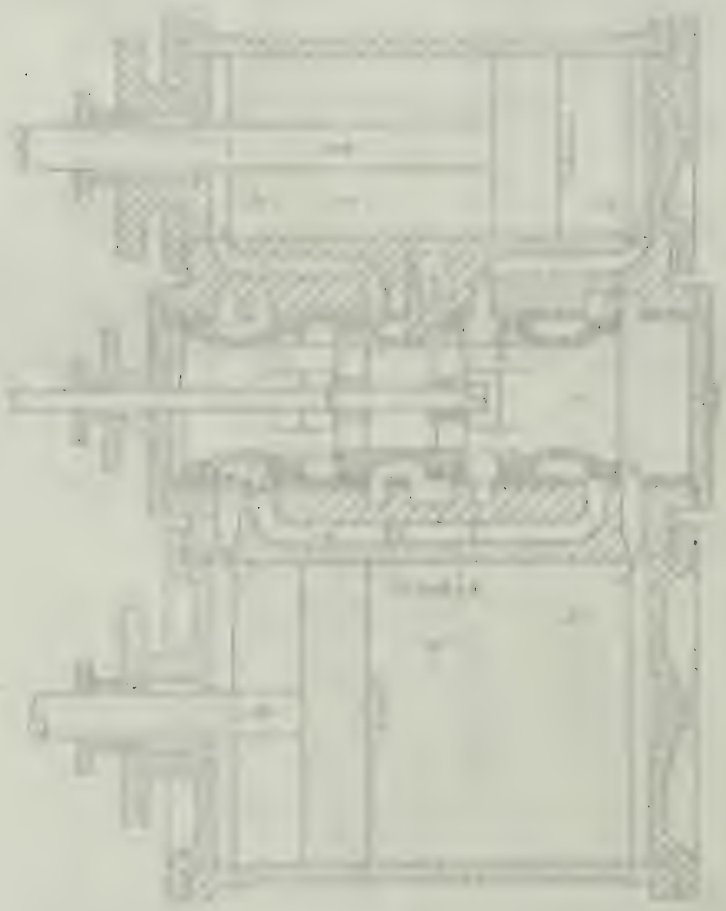


Sections of Piston Valve.





PISTON VALVE FOR FOUR-CYLINDER BALANCE COMPOUND.



-ment of the valve, due to longer ports.
Easier to balance, but no so free to let water in the cylinder escape as the slide valve, sometimes causing broken cylinder heads.

e. Valve Gear.

The valve gear of a locomotive contains all the mechanism that moves and regulates the motion of the valve; and, since there are two valves on a locomotive, there must be two sets of valve mechanisms, or one for each valve. In order that the locomotive may run either backwards or forwards with equal facility, the valve mechanism must provide a means of quickly reversing the direction of rotation of the drivers when necessary. The valve gear must, also, provide a means of quickly adjusting the cut-off for high and low speed as well as other conditions; that is, the engineer must be able, by means of the valve gear, to admit steam into the cylinders for only a small part of the stroke, or for nearly the whole lenght as circumstances may require. The most common mechanism for performing these operations is that known

as the Stephensons link motion, and also the valve motion known as the Walschaert gear. Both employ the link motion; the difference being in the method of producing the desired results.

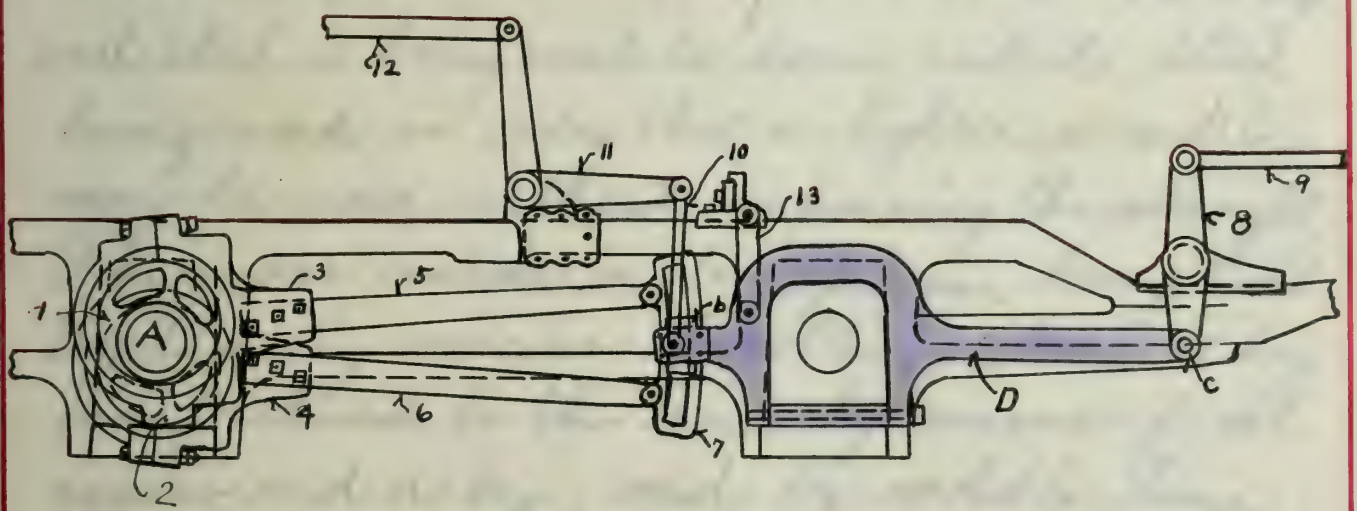
1. Stephenson's Valve Gear.

The "Stephenson Link Motion" is shown on page 101. This illustrates the valve motion on the right, as it would appear on the engine when looking from that side. The left and right motions are similiar, the one being an exact duplicate of the other; therefore a description of the right side will suffice for both.

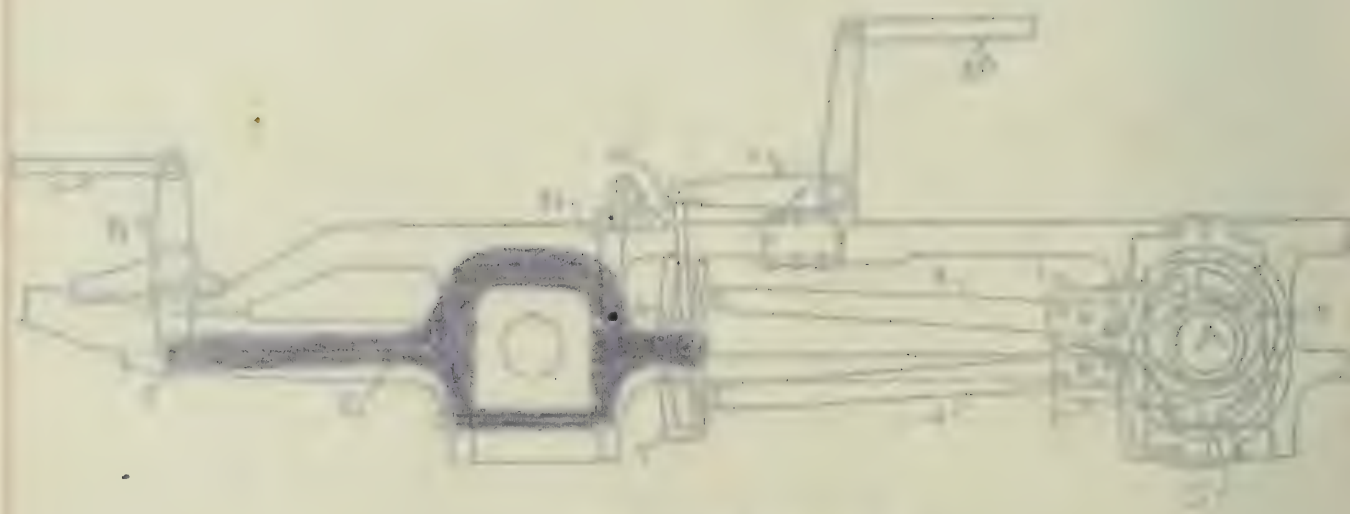
In the figure A represents the driving axle, to which are attached the eccentrics 1+2; 3+4 are the eccentric straps; 5+6 are the eccentric blades, formerly called rods but called blades because of their flatness; 7 is the link; 8 is the rocker box and arms; 9 the valve rod; 10 the link hanger, by means of which the link 7 is connected to the horizontal arm of the tumbling shaft 11; the vertical arm of the tumbling shaft is attached to the reach rod 12, the latter being connected to the reverse lever in the engine

cab. In old locomotives and some of the mod-
-ern ones, the link block b is connected directly to the arm of the rocker box c, but in many modern locomotives the eccentric blades would be rather long to admit of this arrangement, so short eccentric blades are used and a bar D is used to connect the link block b with the pin at c on the rocker box. The eccentrics are generally placed on the main pair of drivers. The bar D is called the transmission bar, of which there is one on each side; they transmit the motion of b to c. Other forms of transmission bars are used, and which are more nearly straight and they do not ~~need to~~ surround the axle as shown in the figure. The end of the transmis-
-sion bar is supported by the hanger 13, which swings on pins. The block b is supported by the rocker box arm at c; or, if a trans-
mission bar is used, the block is supported by this bar.

The link determines by its position what the motion of the valve shall be, or in other words, the engineer governs the motion of the valve by means of adjusting the position of the link with the reverse lever.



Modern Valve Gear.



The duties of the link are two-fold: first, it provides a means of readily reversing the locomotive, since by its means the valve may be governed in its motion by either eccentric; secondly, it provides a means whereby the admission of steam to the cylinders can be readily cut off at different parts of the stroke.

Eccentrics are made of cast iron, although cast steel is being used to some extent. Steel being used in order that a lighter eccentric may be used without impairing the strenght. They are made in two pieces, being held together by means of bolts or studs. They are fastened to the axle by means of set screws and a key, and by saddle keys having teeth on the under side held in place by set screws. The saddle key is used to avoid cutting a key way in the axle, and readily allows the eccentric to be adjusted in a circumferential position about the axle, and gives little trouble in sliping if properly applied. The other method where a key way must be cut in the shaft is not so easily adjusted.

The eccentric straps are made of cast

of the valve from that of the link block.

The tumbling shaft shown in the figure at 11 serves the purpose of lowering or raising the links, thereby governing the valve motion. In doing this, the tumbling shaft is moved by the reach rod connected to the reverse lever in the cab, which is operated by the engineer.

Operating the valve gear:

The details of operating the valve gear will not be dealt with, but the method of producing the results will be dealt with briefly. As shown in the figure, the links is in its central position, and no steam can be admitted to the cylinders. Now, by either raising or lowering the link to its maximum position, the motion of the link block b is governed by the eccentric to which eccentric blade it is nearest to; the eccentrics being placed on the axle in such a position, that one back the engine up and the other runs it forward when in control of the valve. Now, by changing the position of the link from its maximum position towards its central position, the link block b comes under the control of both eccentrics, which

iron, but some are made of brass because it gives better wearing surface. This makes a very expensive eccentric, as they are very heavy; so cast iron eccentrics and straps are used having a brass slip ring for wearing surface. This slip ring is simply a brass ring equal to the width of the wearing surface of the eccentric, and cut into three parts, and placed in between the strap and its eccentric as shown in the following sketch.

This makes a very good eccentric and strap arrangement, and which is much cheaper than using a brass eccentric strap.

The rocker box, containing a shaft with two arms and a box or bearing, serves the purpose of connecting the valve rod with the link block b. This is necessary since the valve rod comes outside of the frames and the link block b on the inside, which could not be connected by a single rod to good advantage. The rocker arms sometimes serve the means of reducing or increasing the motion of the valve, by having shorter or longer arms. It also serves the means of reversing the motion

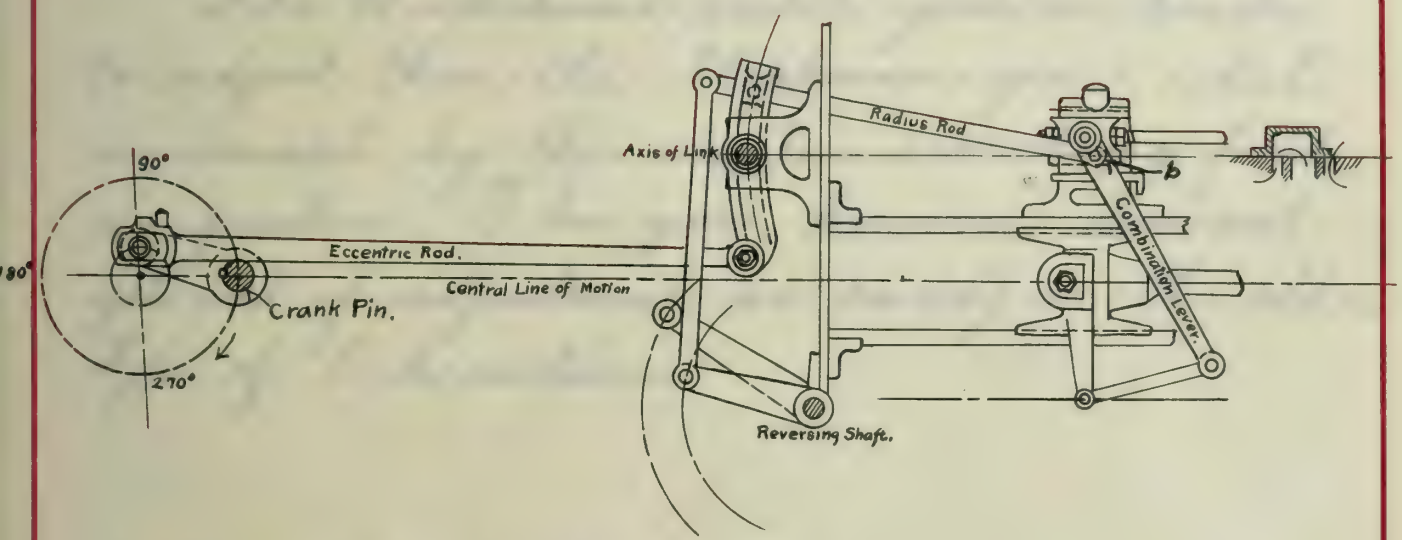
tend to decrease the motion of the valve and regulate the cut-off and other parts of the valve's motion.

In starting out with a heavy train, it is desired to obtain the maximum speed as quick as posible; the only way to accomplish this is to have as high a draw bar pull as posible, which means steam must be admitted nearly the full lenght of stroke. This is done by having the reverse lever in the last notch on the quadrant, or in other words having the link in its maximum position from its central one. After speed has been obtained, the cylinders would use steam faster than the boiler could supply it, if the steam was allowed to enter the cylinder nearly the full lenght of the stroke. To save steam it is used expansively, by having the cut-off come early in the stroke, which is done by means of the reverse lever. Again the cut off governs the speed of the locomotive, in that at short cut-off little steam enters the cylinder, consequently little work is done.

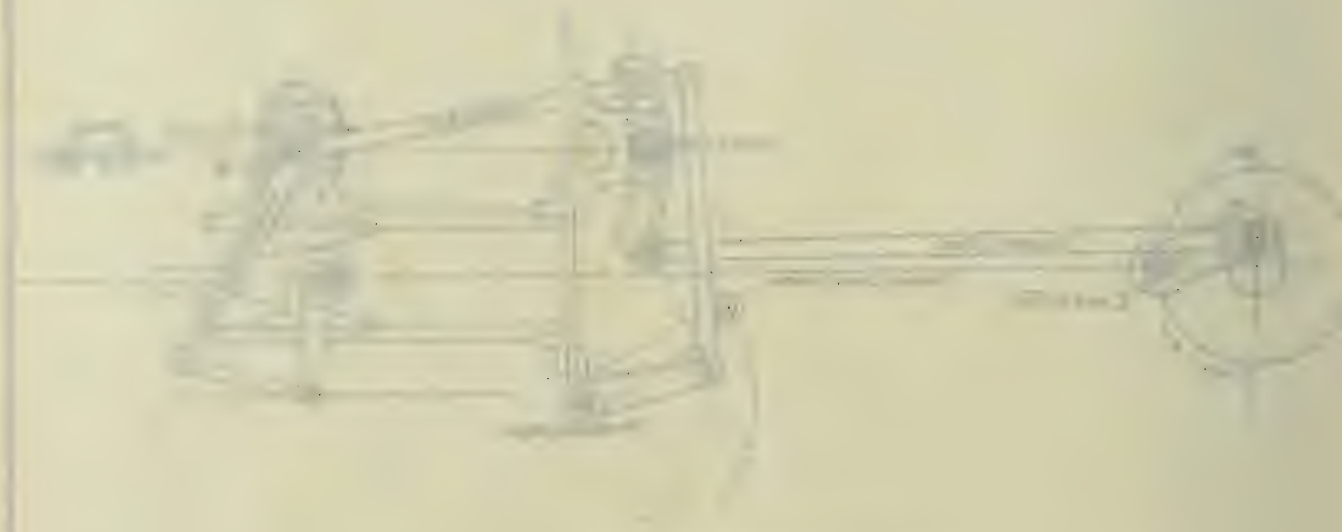
The link, which governs the valve's motion, is controlled by means of the reverse lever.

2. Walschaert Valve Gear.

The Walschaert valve gear is shown on page 107. In this figure the mechanism is shown, which operates the valve. As is shown, the motion of the valve is governed by the crosshead motion as well as the motion of the eccentric on the axle. This valve motion was designed to give the motions to the valve the same as the Stephenson motion, but with the use of but one eccentric, while Stephenson uses two. As but one eccentric is used on the Walschaert gear, it is of necessity set at an angle of ninety degrees from the crank, consequently it can impart no lead to the valve, being without angular advance; therefore, an independent connection to the crosshead furnishes the lead, and as the cross head has always the same stroke, the amount of lead is constant for all points of cut-off. This eccentric consists of an arm placed on the main crank pin on American locomotives. Only one eccentric rod is used, and the cut-off is governed by the position of the radius bar relative to the link, which is easily seen from the drawing.



WALSCHAERT LINK MOTION.



The Walschaert valve motion gives constant lead for all cut-offs and speeds, which is not always desirable.

It is lighter than the Stephenson valve gear. This saving in weight comes principly from the use of a light eccentric arm in the place of two heavy eccentrics and straps as used on the Stephenson motion.

The Walschaert valve gear is harder to adjust than the Stephenson gear; which is caused by the eccentric arm being fixed in position. This gear, however, does not get out of adjustment as easily as the older type of link motion.

f. Connecting Rods.

The connecting rods of a locomotive consists of the main rods and the side rods, the latter ofter being called the side or parallel rods. The main rods connect the crossheads with the crank pins of the driving wheels, this paticular pair of driving wheels being called the main drivers, while their pins are called the main crank pins. The main rods transmit the thrust of the pistons to the crank

pins, thus causing the driving wheels to revolve. The use of the side rods is to connect two or more pair of drivers, thereby increasing the adhesion of the locomotive accordingly. The duty of the side rods is, therefore, to couple the driving wheels together in such a way that the force transmitted by the main rods will be divided among them.

The main rods on the old American type of locomotive are connected to the main crank pins next to the driver, while the side rods are connected outside of the main rods. This arrangement permits of a smaller crank pin being used, since the force applied to the pin by the main rod has less tendency to bend it. On nearly all modern locomotives, the front drivers are so far forward that the main rods cannot be connected to them. In all these cases, the parallel rods are connected to the journal next to the driver on the main crank pins, while the main rod is connected to the outside of the side rods.

In the balance compounds of recent construction, there are four main rods. Up to date these have been attached by two different methods. In the Atlantic type of balanced compounds, the

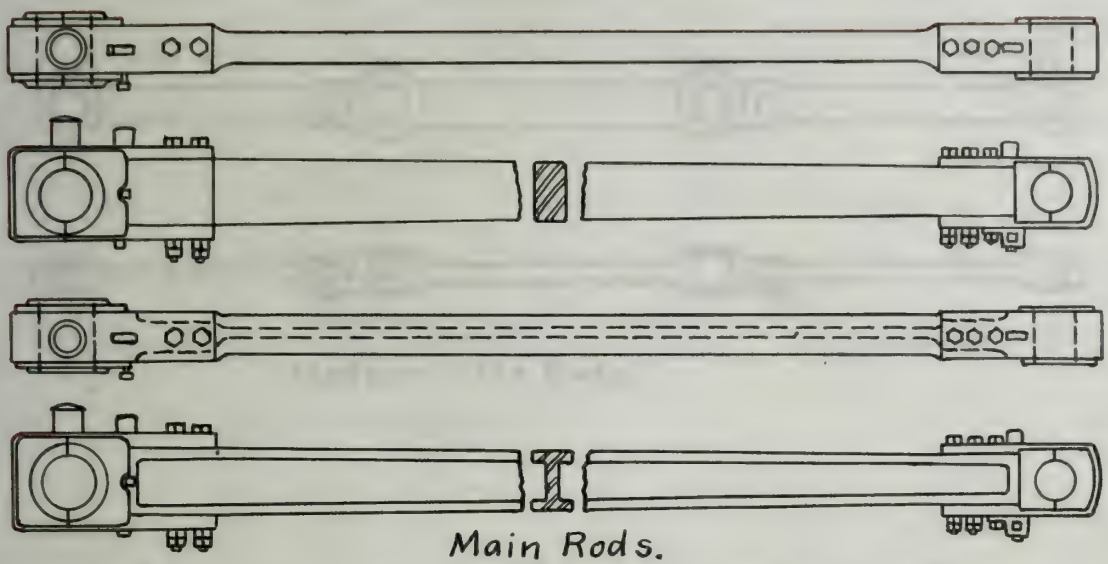
outside main rods are attached to the rear pair of drivers, while the inside rods are connected to the front drivers by a cranked axle as shown on page 122. The outside and inside rods being of similiar construction, with the exception of the outside rod being of greater lenght and the inside rod having a much larger crank journal. In the Pacific type of balanced compound, the inside main rods are connected to the cranked axle of the second pair of drivers, the rod being of peculiar construction as shown on page 112, so as to go around the front axle. The outside main rods of this locomotive are connected to the same pair of drivers as the inside rods are connected to.

The figures on page 112 illustrates various connecting rods in use. The two upper rods are the same except that one is rectangular in cross section, while the other is of **I** shape. These styles of rods were used for many years until a new style of front end was introduced as shown on the same page. Now nearly all the main rods have the solid front end, containing two brasses and an adjustment wedge. This end makes the rod much lighter for the same

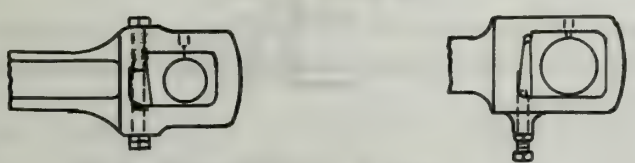
strenght. The new style of back end shown on page 112 is now used on many rods.

The main rods, as is shown in the drawings, contain a brass box at each end, which is adjustable by means of liners and taper keys. The liners are inserted between the key and the brasses; the object being to prevent the keys cutting the softer metal of the brasses. Liners are, also, placed between the brasses and the yoke holding them, when neccessary to lenghten or shorten the main rod.

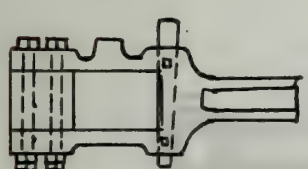
The side rods are usually made in the form of rectangular bars or of I cross section. They are usually made of steel, but may also be made of wrought-iron. The various forms are shown on page 113, which illustrate the old and new style of rod. In the old style of rod, stub ends were used to contain the brass boxes for the crank pins. The new style is to make the rods with solid ends, containing a brass bushing for the bearing. In the strap end type of rods, the wear and play can be taken up by means of a taper key, while in the new style no provision is made for taking up wear. When the solid end rods brasses become worn, they must be replaced by new



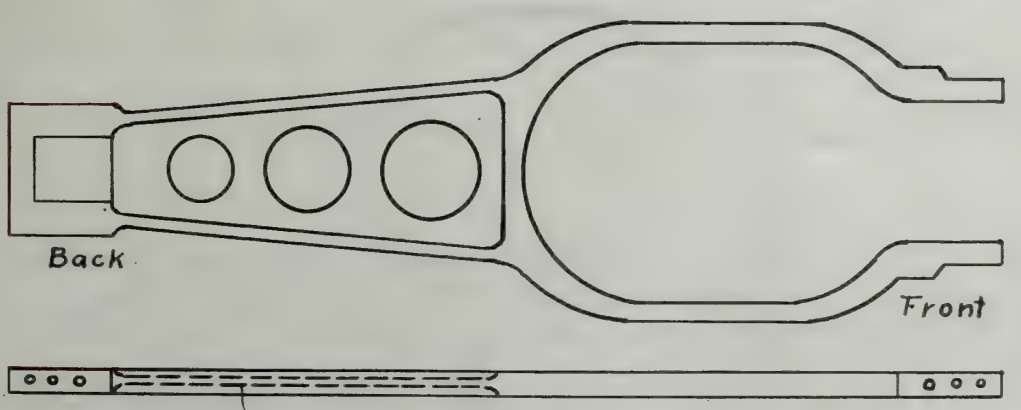
Main Rods.



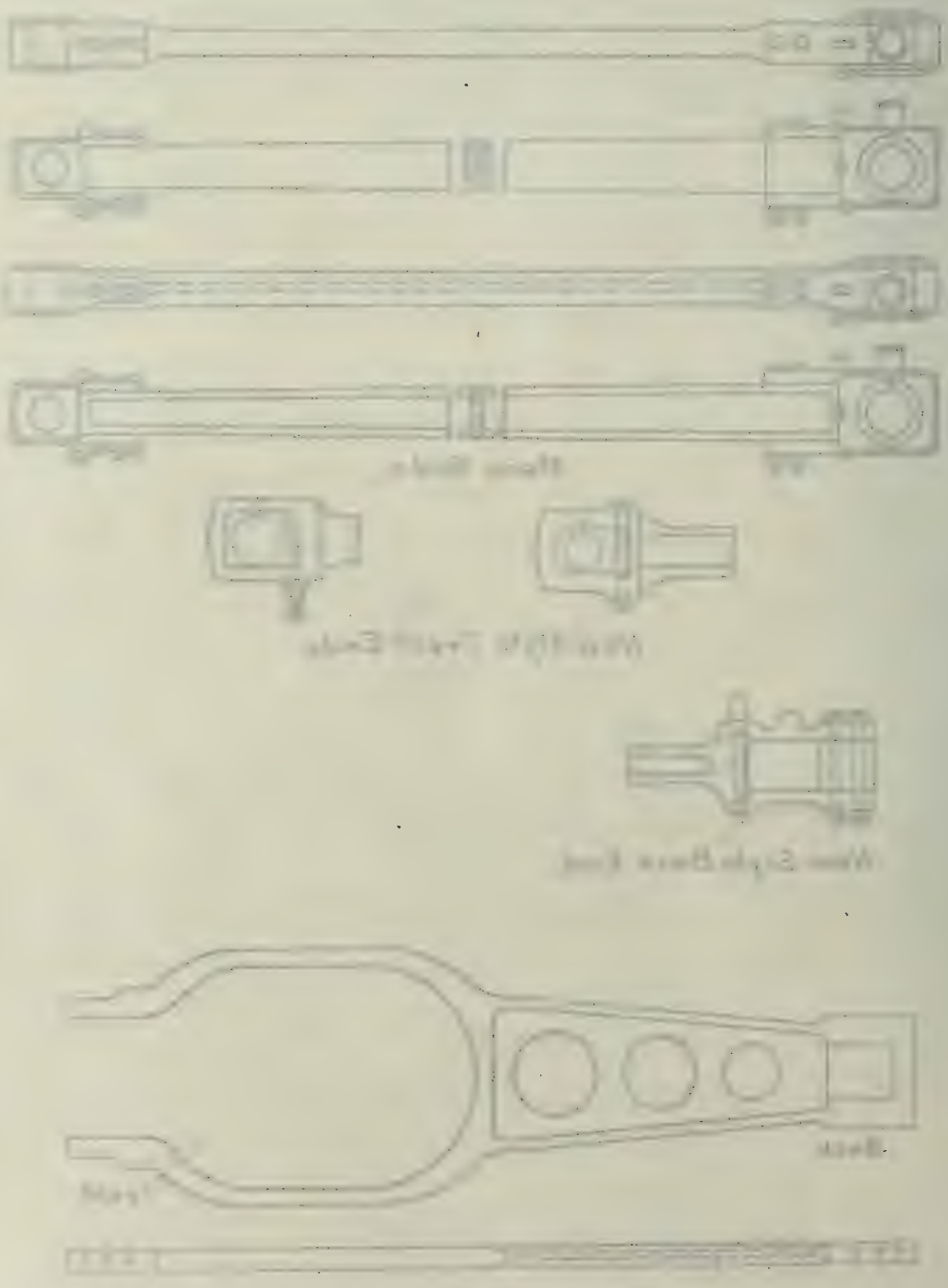
New Style Front Ends.

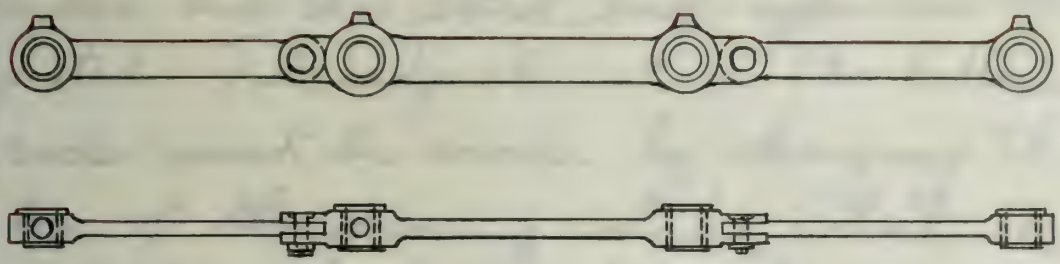


New Style Back End.

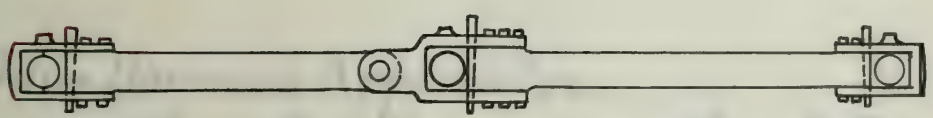


Inside Main Rod Usedon Balanced Compounds
With 3 Pair of Drivers.

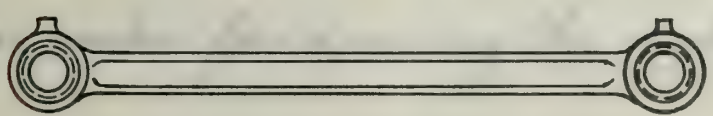




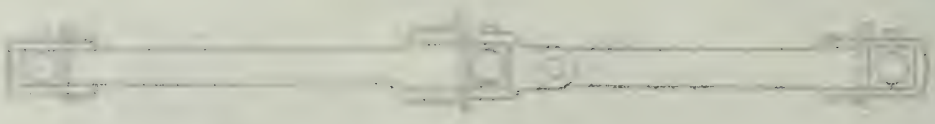
Modern Side Rods.

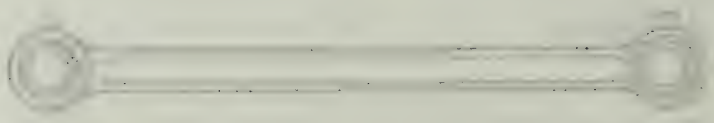


Old Style Side Rods.



Single Side Rod for 4 Driver Locomotive.





brasses. These brasses are made in one piece, turned to the required diameter and forced in place with great pressure. The strap end rods may also be adjusted for lenght of centers, but the solid end type can not be adjusted. The adjustment in the latter style of rods must be made by changing the centers of the driving wheels, which is done by adjusting the driving boxes by means of the shoes and wedges.

g. Miscellaneous Apparatus.

Under this heading comes the following:

1. Lubricators for lubricating the valves and cylinders.
2. Cylinder cocks for draining the cylinders of water.
3. Starting valves used on compound locomotives, so as to admit high pressure steam to the low pressure cylinder in starting or on heavy grades.
4. Relief valves to prevent a vaccuum forming in the cylinders or valve chamber, when not using steam while the engine is in motion.
5. Oil cups to oil the various journals and rubbing

surfaces.

The lubricator is placed on the back part of the boiler and iside of the cab, where the engineer may readily see it. Small copper pipes are placed under the boiler lagging and next to the boiler, connecting the lubricator with the steam chests; the oil flowing along the pipe. One lubricator lubricates both cylinders and also the air pump.

The cylinder cocks are operated from the cab by means of rods and levers.

C.
Running Gear.

1. Introductory & History.

In this connection will be treated the running gear of the locomotive, that is that part that has to do with the motion and carrying of the locomotive on the rails. This will include the drivers which may, also, be said to belong to the engine mechanism.

In the early locomotives, the driving gear was very inferior to what it is today. The drivers consisted of wooden wheels, with thin iron bands for tires. The frames were of wood. No springs or equaliging levers were used, to equalize the weight between the drivers, in order to make the engine ride easier. Early American locomotives are shown on pages 66 to 70. From these the construction of the running gear of each may be readily seen.

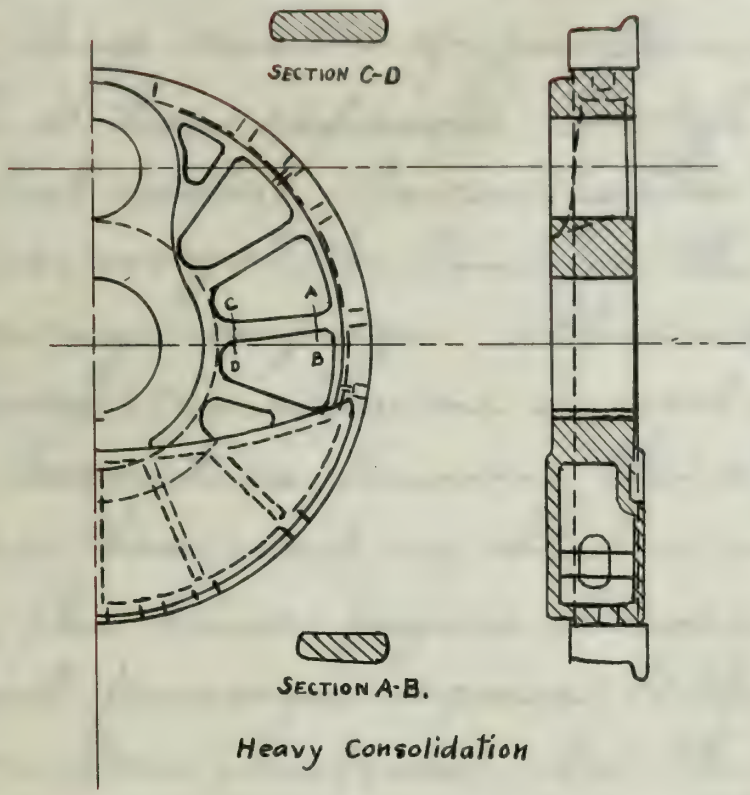
2. Drivers:-

a. Centers.

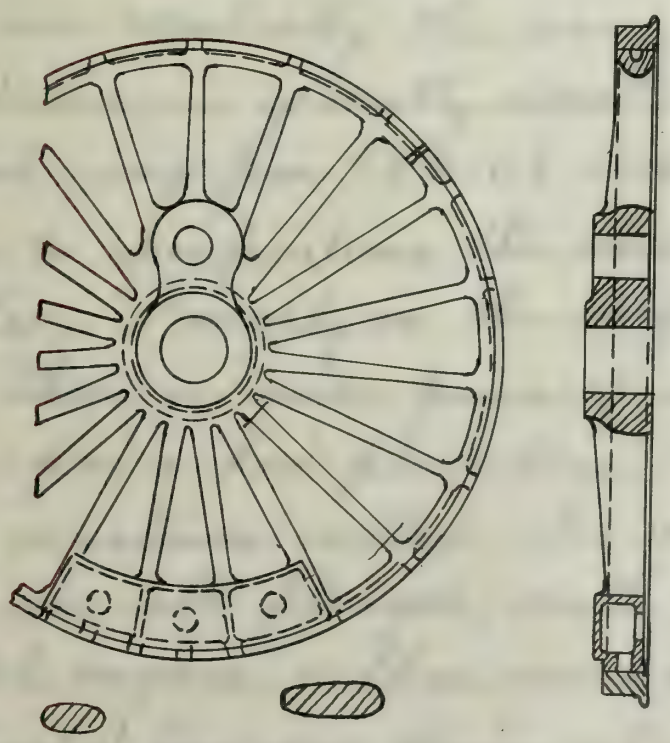
Drawings of driving wheels are shown on page 118. A driving wheel consists of a wheel center on which is shrunk the steel tire. The driving wheel centers were formerly made of cast iron, but now steel castings are becoming more general; in some locomotives, however, the main drivers are made of steel and the others of cast iron. The spokes are usually cast solid, but some are cast hollow. The rim is cast hollow as shown in the drawings. The hub, the crank pin, and the counterbalance complete the driver. The counterbalance is cast with the wheel, either hollow or solid. When cast hollow, lead is afterwards poured into the core holes, in order to balance up the drivers.

b. Tires.

The tires are made of a good grade of tough steel, and are shrunk on their centers. The wheel center is turned, and the tire is bored smaller in diameter - usually $\frac{1}{80}$ to $\frac{1}{64}$ inch per foot in diameter of center according to material in the center - than that



Heavy Consolidation



Fast Passenger.

of the wheel center. The tire is then heated by means of a large number of gas flames in a circle, until it has expanded enough to slip over the wheel center. In cooling, the tire contracts causing it to bind on the center.

The drawings on page illustrate two types of drivers: the upper one is used on heavy consolidation locomotives, however, the style is the same as those used on all low wheel locomotives; the lower figure shows a type used on fast passenger engines. Other drivers might have been illustrated, but the constructive features are essentially the same as the above.

The drivers, as generally constructed have flanged tires; which vary from 4 3/4 to 6 1/4 inches in width, according to specifications; the usual width is 5 1/2 inches. Formerly in the larger locomotives, having three or more pairs of drivers, one or more pairs had plain tires, or blind tires, as they are sometimes called. In modern practice, the tires are all flanged, with the exception of switch engines, or those used on sharp curves.

The flanged tires are shown at A, and the plain at B, on the next page. The plain tires are made wider than the flanged ones; they must be made to suit the curves over which the engine

Tires.

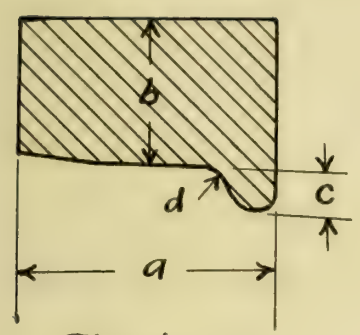


Fig. 1.

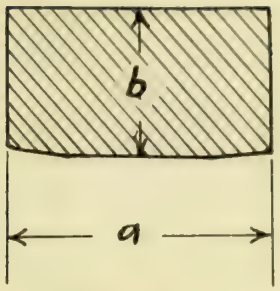


Fig. 2.

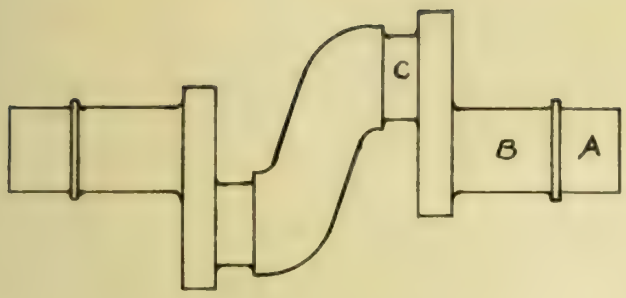
must run, and are made from 6 to 8 inches wide.

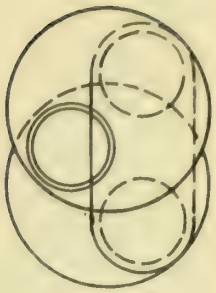
The cross-section views of both tires are shown above; a = width of tire, b = depth or thickness, c = height of flange, and d = clearance for the rail, which is a fillet having a radius of $\frac{1}{2}$ to $\frac{5}{8}$ inches. The depth of the new tires is from $3\frac{1}{2}$ to 4 inches, while $1\frac{1}{2}$ inches or more is the least thickness allowed at the last turning of the tire.

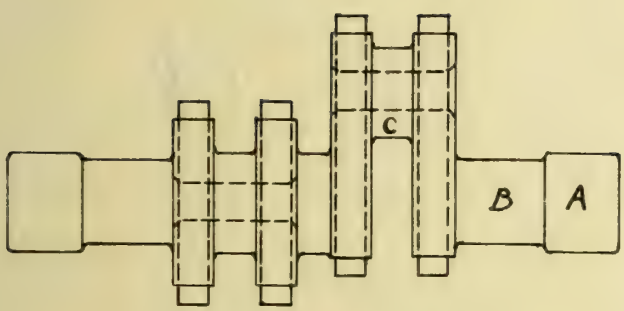
C. Axles.

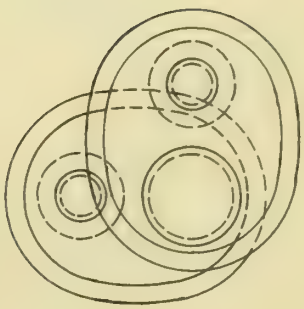
The driving axles are made of forged iron or steel. On page 122 are shown different styles used in locomotive construction. The part A is fitted into the driver hub, and is usually turned $\frac{1}{8}$ inch less in diameter

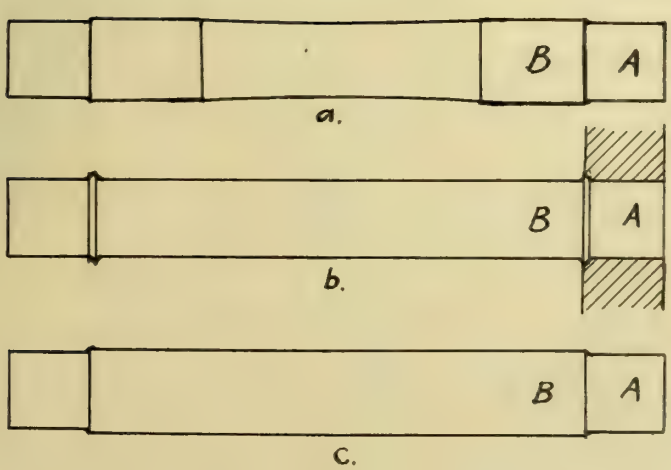
than the journal B of the axle, this gives sufficient shoulder for all practical purposes.
The upper drawings show the cranked axles used on the four cylinder balanced compounds, to which are attached the inside main rods.
Of the lower axles b is the best of the three.
Here the diameter of the journal and wheel fit are equal; a filleted collar being formed on the axle when it is turned up in the lathe, against which the hub of the wheel is pressed, the hub being counterbored to receive it. No sharp corners should be turned on the axle, since it weakens the strenght by allowing a fracture to be started more easily.
The driving wheel hubs are bored slightly smaller than the diameter of the wheel fit on the axle. Then the centers are forced on the axle, with a very high pressure. This pressure varies between 60 to 125 tons; the later pressure is used on the heavest axles and steel wheels.
The centers are pressed on the axles, with the tires off, since after the tires are on, the pressure of the hub on the axle is greatly increased.


C
B
A




C
B
A




B
A
a.
B
A
b.
B
A
C.

d. Counterbalancing.

The drivers of a locomotive must be counterbalanced to overcome the effects of inertia of the rods and reciprocating parts. If a locomotive was not counterbalanced, at high speeds it would leave the track due to the difference between the maximum and minimum rail pressure. This readily seen from the following example:

The weight on main drivers = 60,000.#
Cylinders 20 x 26 inches
Diameter of drivers = 80"
Speed per hour. = 80 miles.
Weight of rods on main crank pin = 600#
" " crank pin and hub = 300#

Therefore we have 900 pounds at a radius of 13 inches from the center revolving at the speed of $\frac{13}{40} \times \frac{80 \times 88}{60} = 38.2$ feet per sec.

From the formula for centrifugal force

$$F = \frac{WV^2}{gR}$$

or $$F = \frac{900 \times \overline{38.2}^2}{32.2 \times \frac{13}{12}} = 37,640.\#$$

The centrifugal forces due to these revolving weights would, therefore, cause a maximum force of 30,000. + 37,640. = 67,640.# on the rail, and

a minumum force of 30,000. − 37,640. = − 7,640 #.
The former force would cause a fearful pound on the rail; while the latter would lift the main driver, if not all the drivers, from the rail and the engine would not stay on the rails, while running at high speeds. Therefore the revolving weights in the wheels must be counterbalanced.

The reciprocating parts must also be counterbalanced, so as to overcome the inertia forces due to them. These must not be wholly counterbalanced, however, or there will be an excess balance, which will cause excessive and minimum weights on the rail as proved in the last paragraph. This would be caused by the reciprocating parts exerting no inertia forces on the crank pin at the middle of the stroke, when the counterbalance put in the wheel to counterbalance these parts would have no oposite force to equalize it. Therefore all this excess counterbalance, which in many cases is nearly as great as the counterbalance of the revolving parts, would cause nearly as great or a less force than determined by the above paragraph, and which would be more disastrous, perhaps, than to not have the reciprocating weights

counterbalanced at all. By not having the reciprocating parts balanced at all, the drivers would be nearly perfectly balanced at the topmost and lowest positions of the crank pin; between these points the wheel would not be balanced. Again the drivers could be nearly balanced, by having the the reciprocating parts balanced with the other rotating weights at the ends of the stroke; between these two points the wheel would not be balanced. The only method by which a driver may be balanced as nearly correctly as posible, is therefore, to balance the revolving weights and part of the reciprocating weights. This method is used in counterbalancing all modern locomotives, except that of the four cylinder balanced compound. A rule used for counterbalancing the drivers by one of the largest railroads in this country, and similiar, if not like other rules used on other railroads is:

a. Counterbalance all revolving weights attached to the wheel; considering the back end of the main rod as revolving weight.

b. Counterbalance $\frac{2}{3}$ of the reciprocating weight, dividing the weight equally between all the

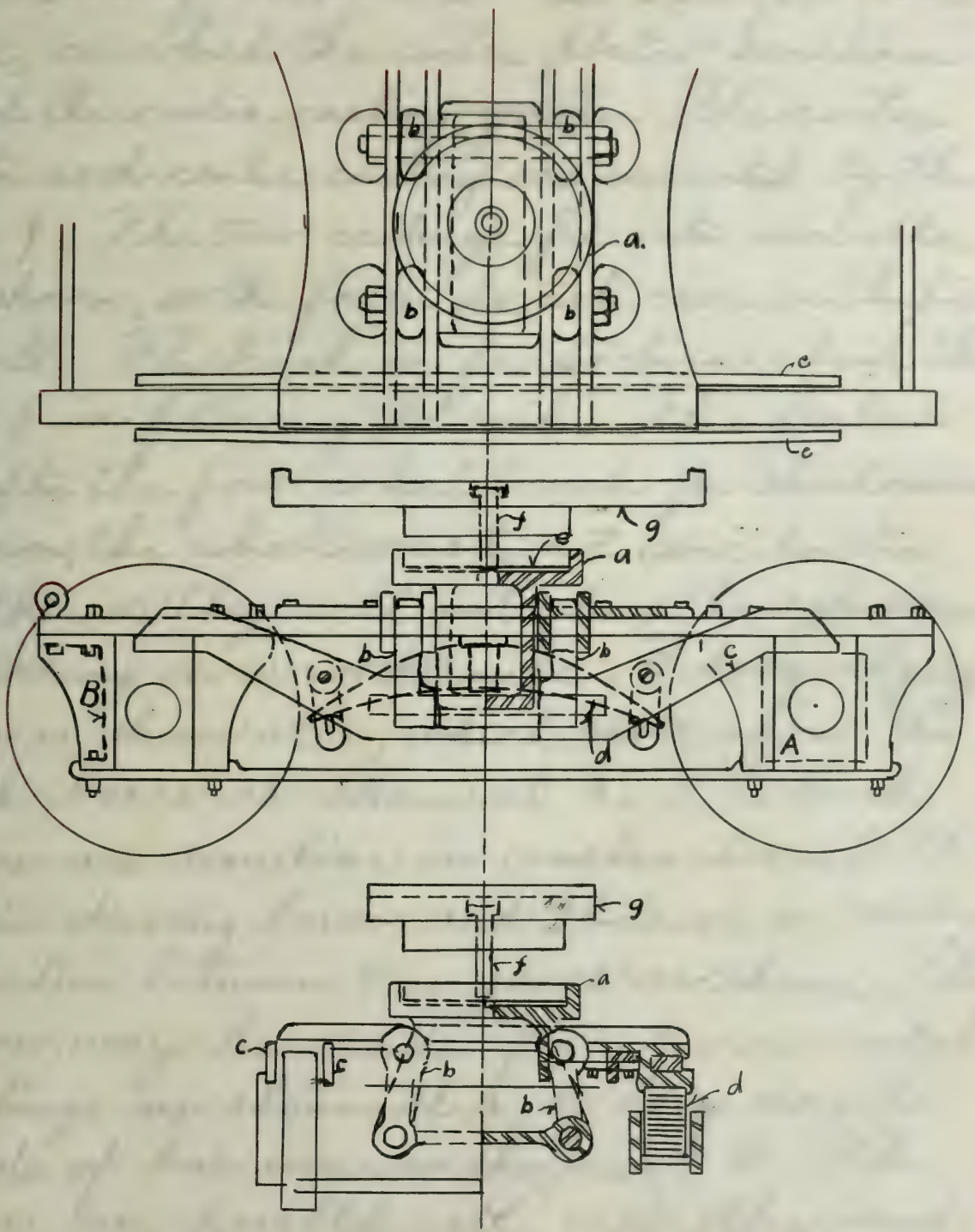
drivers.

The rule b is generall observed by all locomotive builders, but rule b has some modifications with the various roads and locomotive builders.

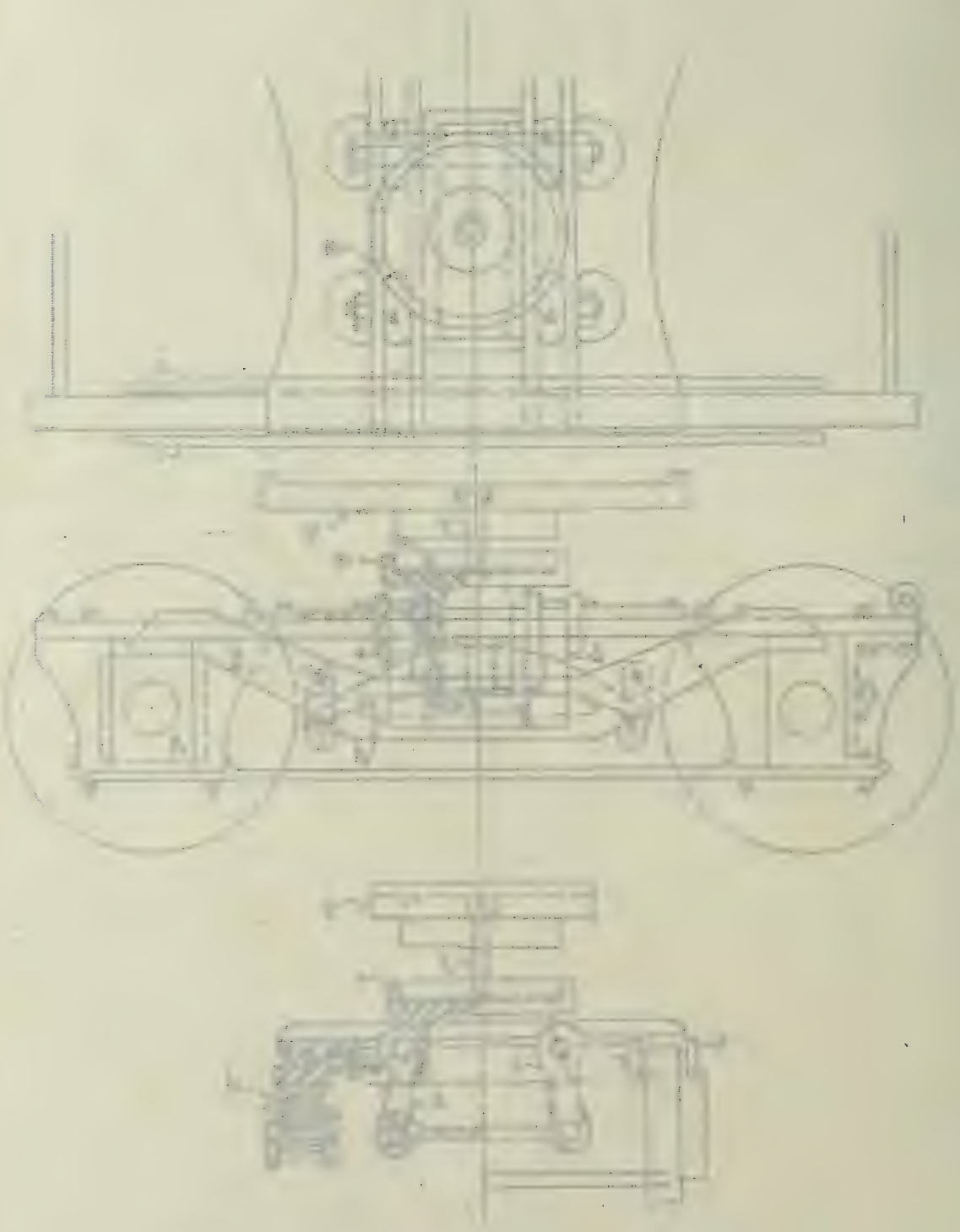
3. Front Truck.

The early locomotives had no trucks. They were invented in 1832, when the locomotive was in its ifancy. They are used to carry part of the weight, and in guiding the locomotive about curves. Two styles of locomotive trucks are in use: the four wheeled and the two wheel truck. The former is know as the swival truck, and the latter as the Pony truck. The wheels vary from 28 to 36 inches in diameter, depending on the size of the cylinders and the amount of clearance for the wheels. Many of the modern trucks have wheels 33 inches in diameter. The old trucks had solid cast iron wheels, but modern practice uses spoked wheels, with steel tires.

A modern type of four wheel truck is illustrated on page 127. It consists of a frame made of wrought iron or steel, to which are bolted the cross bars which support the hangers.



Four Wheeled Locomotive Truck.



These hangers support the center casting a. This center casting contains several steel plate liners at e, on which the center plate - sometimes called the center casting-grests. The center plate and center casting are connected by the pin f. The two castings fit into each other as shown, so the forces do not come on the pin at all. The truck is free to turn about the pin f in following the rail. This feature adapts the four wheel truck for short curves, however, the wheels must not come too close together or they will not clear the cylinders in turning on curved tracks. The equalizing lever is shown at C, which rests upon the truck boxes as shown at A. The truck boxes are similiar in construction to the main driving boxes, and slide in a vertical direction between two jaws as shown These jaws may be made of cast iron or steel castings as shown at A, or they may be made of bar iron as shown at B. The jaws are parallel with each other, and no shoes and wedges are used as in the main driver boxes. To the equalizer levers C is attached the spring d, by means of hangers as shown. This spring holds the

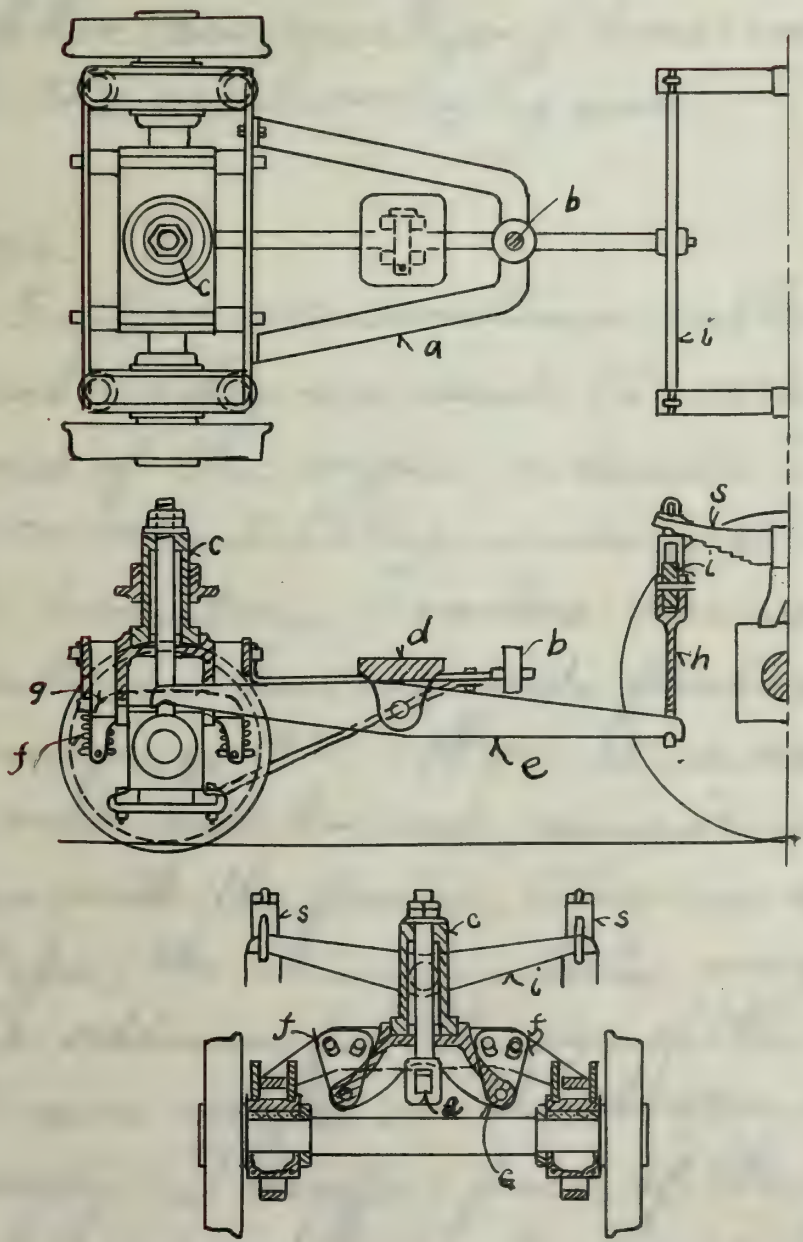
frame of the truck off from the top of the truck boxes, so that the front end of the locomotive will not be rigid, but will ride easy.

A two wheel truck is illustrated on page 131. This is commonly called a pony truck, and is used on many locomotives. It consists of a rectangular frame, to which are attached the truck box jaws. A V shaped frame a called the radius bar, is shown bolted to the frame. This bar extends under the engine, and is connected to the main frames by a cross piece (not shown), and the pin b. This allows the truck to swing laterally about the pin, thus adjusting itself to the curves of the track, while at the same time it is kept from turning about the center c. The bottom part of the cylinder casting rests upon the center casting d, which is connected to the truck equalizer lever e as shown. This lever supports the front end of the engine in the following manner: The back end is connected to the hanger h thence by the transverse equalizer i to the main spring S; while the front

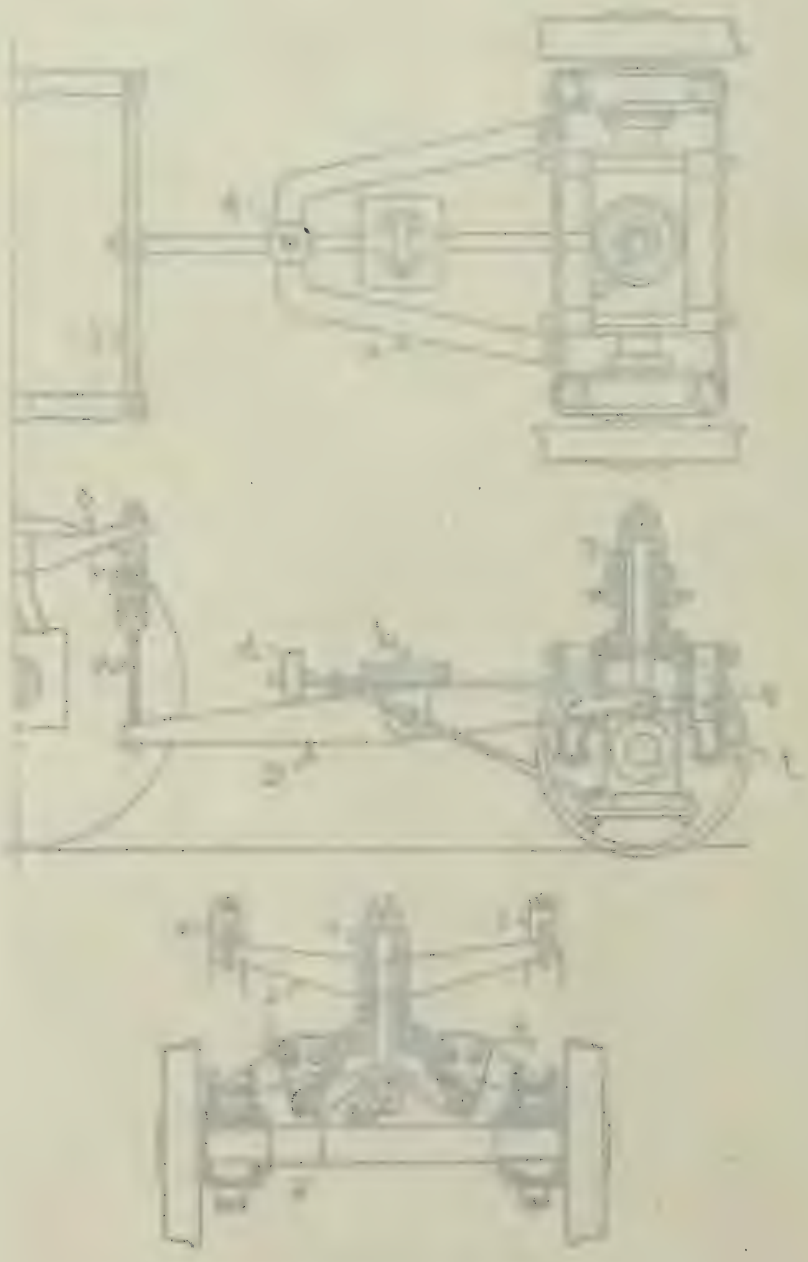
end is connected to the truck king bolt hanger as shown. The truck king bolt is supported by the hangers f; which as shown are three center hangers, but may also be two center hangers. The outside casting at c is fastened to the main frames of the engine. The truck boxes are similar to those of the four wheel trucks. The lower end of the jaws are braced to the radius bar a as shown. The frame of the truck is supported by the coiled springs f and the equalizing levers g, which prevents the frame from resting on the truck boxes. The other details can be seen from the figure.

In passing a curve, the engine tends to keep straight ahead, while the flanges of the truck wheels compel the truck to follow the curve In consequence of this, the entire truck swings laterally; that is the truck turns about the pin b instead of turning about the center c.

This form of pony truck relieves the engine of a large proportion of the shocks and jars due to the roughness or irregularities in the track, because the jars and shocks are transmitted to the main carrying gear springs



PONY or 2 Wheeled Truck.



as well as the truck springs; these absorbing the shocks. Some pony truck have no equalizing lever, so the truck springs are the only means by which the jars and shocks are absorbed, consequently the engine does not ride so easy and steady as one, containing a truck equalizing lever. The four wheel trucks seldom have an equalizing lever connecting it with the main carrying gear.

4. Trailers.

The trailers are sometimes called the trailing truck. They are used to carry the back end of the engine, where it is not desirable or convenient to use drivers at the back end of locomotive. Trailers are used mostly on locomotives having wide fireboxes as shown on page 145. Here it is seen that a driver could not be used, since it would interfere with the firebox. Also in a locomotive of this type, the driving wheels may have sufficient adhesion for the size of the cylinders, so that more weight on the drivers is not neccessary. Therefor part of the weight may be carried on a trailer, which at the same time will cause the engine to ride

more steady. On some locomotives it is not neccessary to have a trailer to allow for a wide firebox, as is shown on the consolidation engine on page 147. Here the drivers are small enough in diameter to allow them to be placed under the firebox. This is also shown on the Mallet compound on page .

The trailer is made in two general styles: with a frame coming outside of the truck wheels, and the frame coming on the inside. The outside frame for the trailer is shown on page 145; it is seen here that the boxes come outside of the wheels. The boxes are placed on the inside of the wheels as on the main drivers, when the frame comes on the inside of the trailers. The inside trailer boxes are similar to the main driving boxes. Those that are placed on the outside of the wheels are larger, but somewhat similar to ordinary car truck boxes, having a removable brass casting, which can be quickly replaced in repair work.

Trailer wheels are made of cast iron or steel castings, and have spoked centers, with steel tires. The generally range from 36 to 50 inches in diameter, depending on the

clearance, which in turn may depend on the diameter of the drivers.

5. Driving Boxes.

Two types of driving boxes are shown on page 136. The cast iron box in fig. 2 is the old type of driving box, which is still in use to some extent. The modern locomotives are usually equipped with cast steel boxes similar to fig. 1. The old boxes were made of cast iron, while the usual practice now is to make them of cast steel. A is the driving box, and B is the oil cellar which is filled with oil soaked waste that keeps the bearing well lubricated. The cellar is kept in position by the pins as shown. The flanges on the box serve to hold it in place, the jaws and wedges fitting in between the flanges. The holes a receive the legs or lugs of the spring saddle. C is the driving box brass, or journal bearing. This brass is forced into place with great pressure. The driving boxes are very heavy, weighing from 300 to 500 pounds each, according to the size of the locomotive. They must be very heavy, when

the size of the driving journals are taken into consideration, they being as large as 9X12 to 10X13 inches for heavy modern locomotives. The holes shown at b are oil holes, which lubricate the bearing.

A new style of cellar box has recently been introduced, which lubricates the journal by means of grease, which is pressed up against the journal. This has in general given satisfaction, but in some cases has been very dissatisfactory. The advantage of this contrivance is economy, grease being much cheaper than oil.

The driving boxes and truck boxes must support the entire weight of the locomotive with the exception of the drivers and trucks, the side rods and the rear end of the main rod. The weight on the driver boxes for modern locomotives is between 20 and 30 thousand pounds. The area of the journal supporting this is between 100 and 130 square inches, so that the pressure may be said to be between 200 and 250 pounds per square inch, which is not excessive.

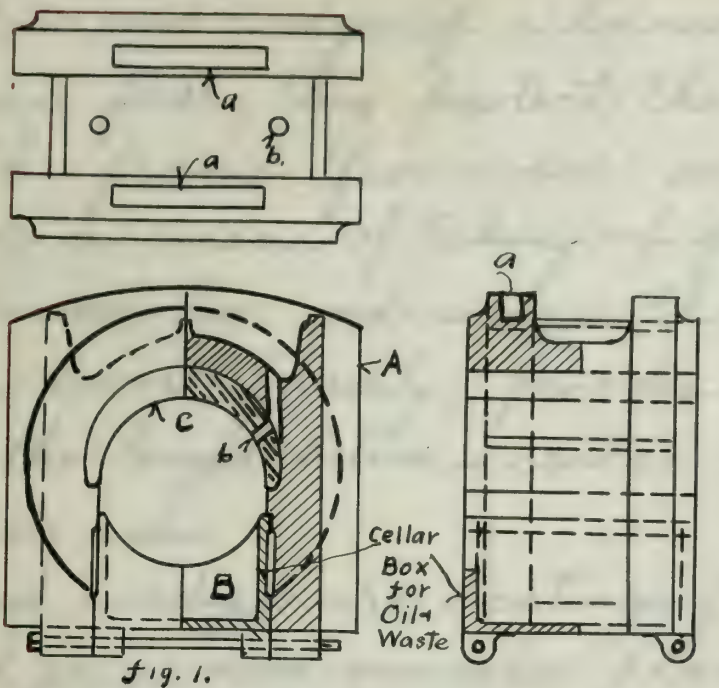


Fig. 1.

Cast Steel Driving Box.

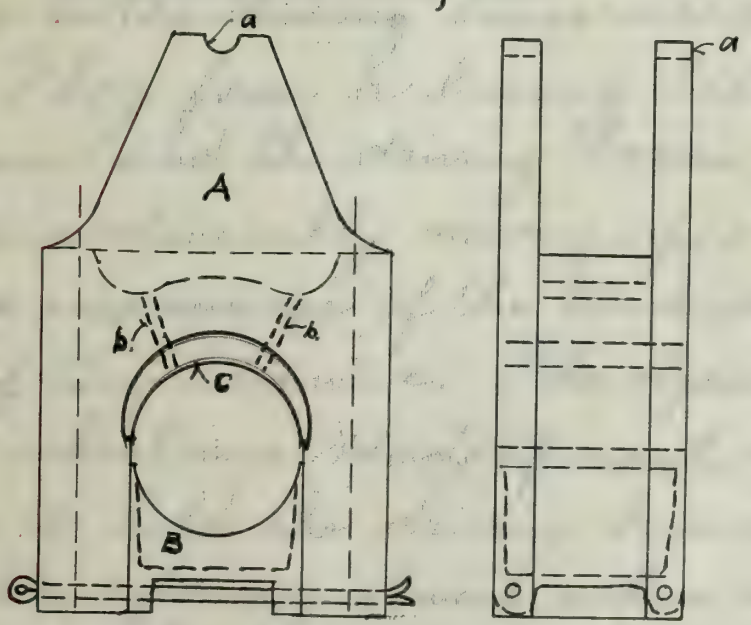


Fig. 2.

Cast Iron Box

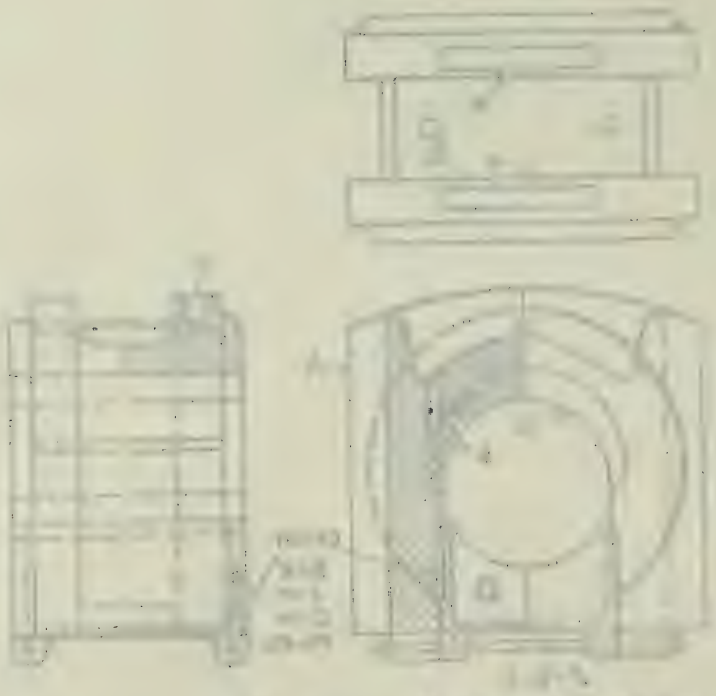


Fig. 1.
Coal Sieve Framing Box.

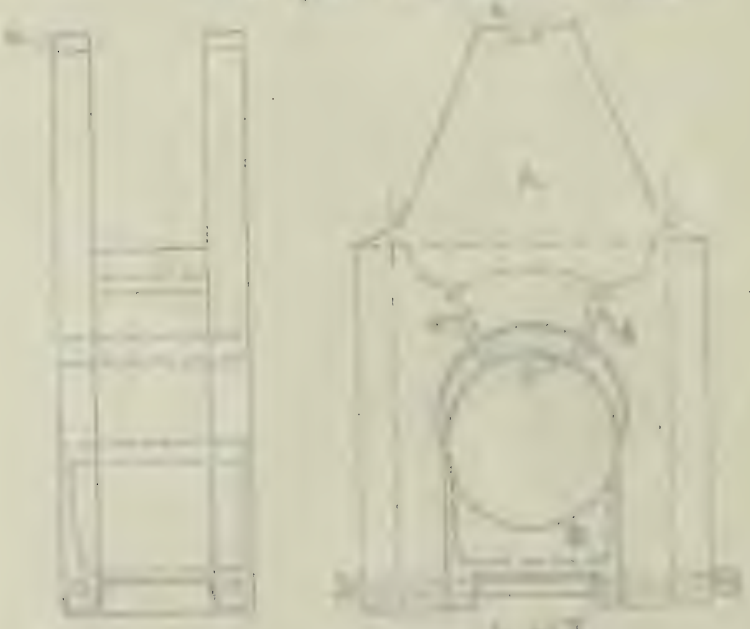


Fig. 2.
Coal Iron Box

6. Shoes & Wedges.

The shoes and wedges of a locomotive serve three purposes: first, they protect the legs or jaws of the frame from wear; secondly, they provide a means of taking up play between the journal box and wedges that may result from wear; thirdly, provides a means of adjusting the lenght between centers, so as to fit the side rods.

Shoes and wedges are castings fitted to the pedestal jaws and are also planed to fit the grooves on the driving boxes as shown on page 136. They form a bearing between the pedestal jaw and the driving boxes, as the boxes are continually moving up and down due to the unevenness of the track and the swinging of the locomotive. The object of these castings, - which are made of cast iron or brass, - is to hold the driving boxes in place and to allow for adjustment when necessary. This adjustment is for the purpose of taking up wear, and adjusting the lenghts of centers between the drivers, so as to have the crank pins fit the side rods. The side rods of a modern locomotive as shown on page 113, being

of fixed lenght, this means of adjustment is neccessary. This adjustment is made by having the main driving boxes shoes and wedges fixed in place, as a starting point to adjust the other boxes by. Thin liners may be put in between the shoe and the jaw, or metal may be removed from the former if it is too thick. The adjustment of the taper shoe is then made, so that the box will work freely in the jaws and not have too much play. This is done by placing liners in between wedge and pedestal brace as shown at e in fig. 2 on page 139; or, if the wedge is that show at B fig. 1, the stud e adjists the wedge as shown.

In the figures; A is the shoe; B the wedge, the taper of which is usually 1/8 in 12; C shows the pedestal braces, which support the jaws of the frame as shown. A and B are usually made of brass, but may also be made of cast iron. The figures show one straight and one taper jaw. The straight is placed nearest to the cylinders, as it is then easier to maintain a fixed distance between the cylinders and the driving axles. Fig. 1 shows one form of jaw in which the shoe is adjusted in height by the nuts e and d. In fig. 2 the shoe

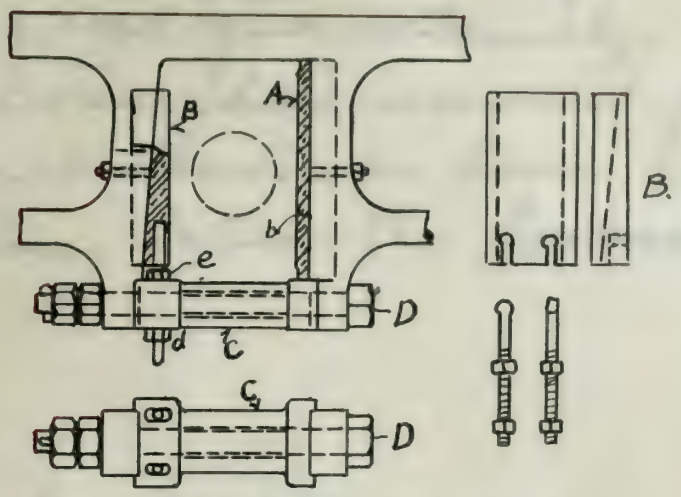


Fig. 1

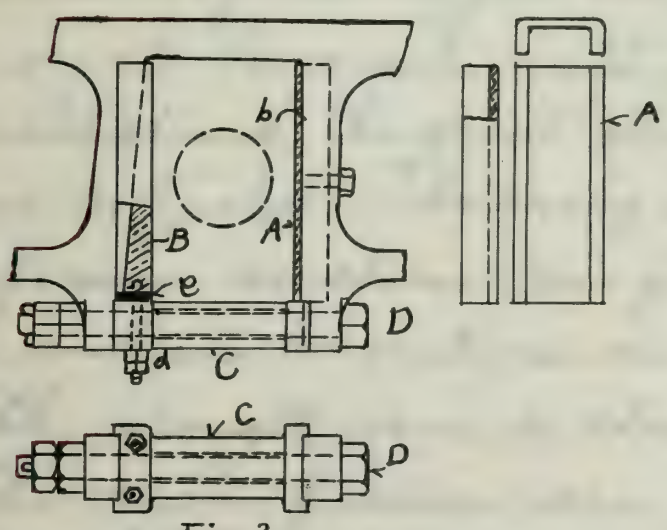


Fig. 2.

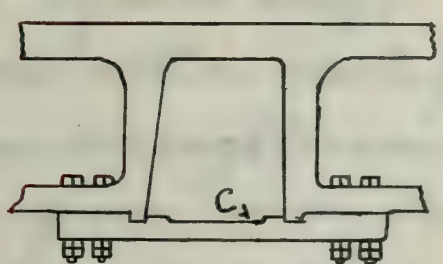
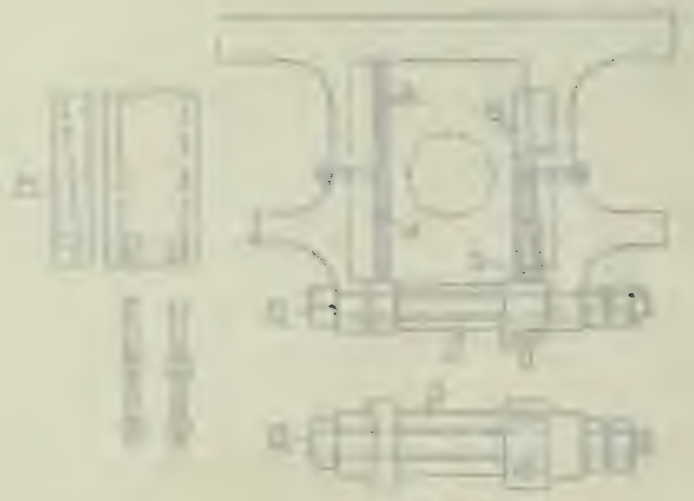
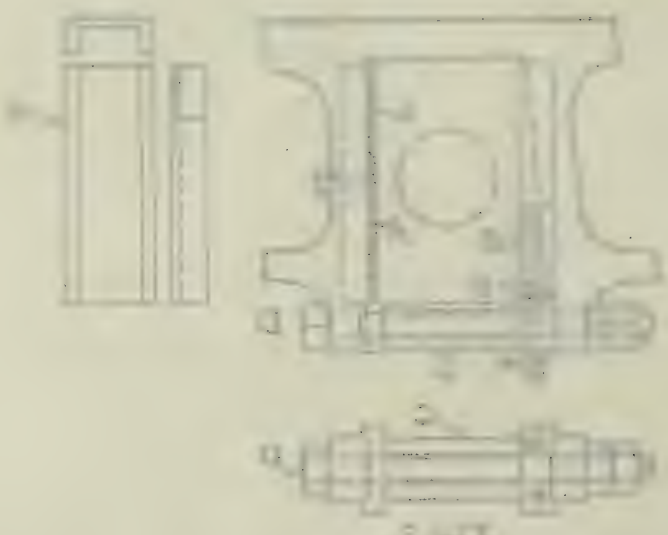


Fig. 3.





is adjusted by placing diners at e and tightening the nuts d on it. In fig. 3 the form of shoe used is that shown at B in fig. 1. This form of pedestal brace is used quite extensively.

Straight cast iron shoes are used for wearing surfaces on the trailer boxes, to furnish a wearing surface between the box and the frame.

7. Frames.

The frames of a locomotive, must support all the mechanism of the engine and boiler. Therefore, it must be made with sufficient strenght to withstand the great strains to which it is subjected. The early locomotives had wooden frames as shown on pages 66-70, but the modern locomotives are all equipped with wrought-iron or steel frames. In Europe, the main frames are made of steel or wrought-iron plates riveted together in the required shape. In this country, the frames are either cast from steel, or hammered from wrought-iron. Cast steel frames have given more trouble on account of breaking than wrought-iron frames. Steel frames are much stronger, and no doubt

in the future, the steel will be given such treatment as will make them more durable than the wrought iron frames.

There are many different forms of frames in use. The frames shown on pages 144-145 are made in three parts, the main frame b, the trailer frame d, and the front part or rail of the frame c, called the splice. This form of frame is used on the Atlantic type of passenger engine, having a wide firebox with outside bearings for the trailers. It will be noticed that the trailer frame comes out much wider than the main frame. This is to allow the bearings of the trailer to come outside of the trailer wheels. The trailer frames are connected to the main frames by a steel casting shown at a; the connection being made by having the joints fit well, and fitted bolts driven into reamed holes, and also having a taper key as shown at a'. The joint shows the method by which this is done. This frame was patented on January 1, 1901, being first used the year before to facilitate the use of wide fireboxes on high wheeled locomotives. This frame also shows the general construction of frames used on other types of locomotives having

wide trailer frames. The trailer frames of the Pacific (4-6-2) and the Prairie (2-6-2) types are similar to the one just described.

Another type of frame used on the Atlantic type of passenger locomotive is shown on page 146 in fig. 1. Here the frame is in two parts, the front rail, and the main frame. Here the back of the frame is much lower than the main part, so as to make room for the bottom of the firebox. The firebox is wide and comes out over the top of the trailer wheels. This frame serves the purpose of using a wide firebox as well as the former one described, and is much easier to make; however, the locomotive is said to be steadier with the wide trailer frame.

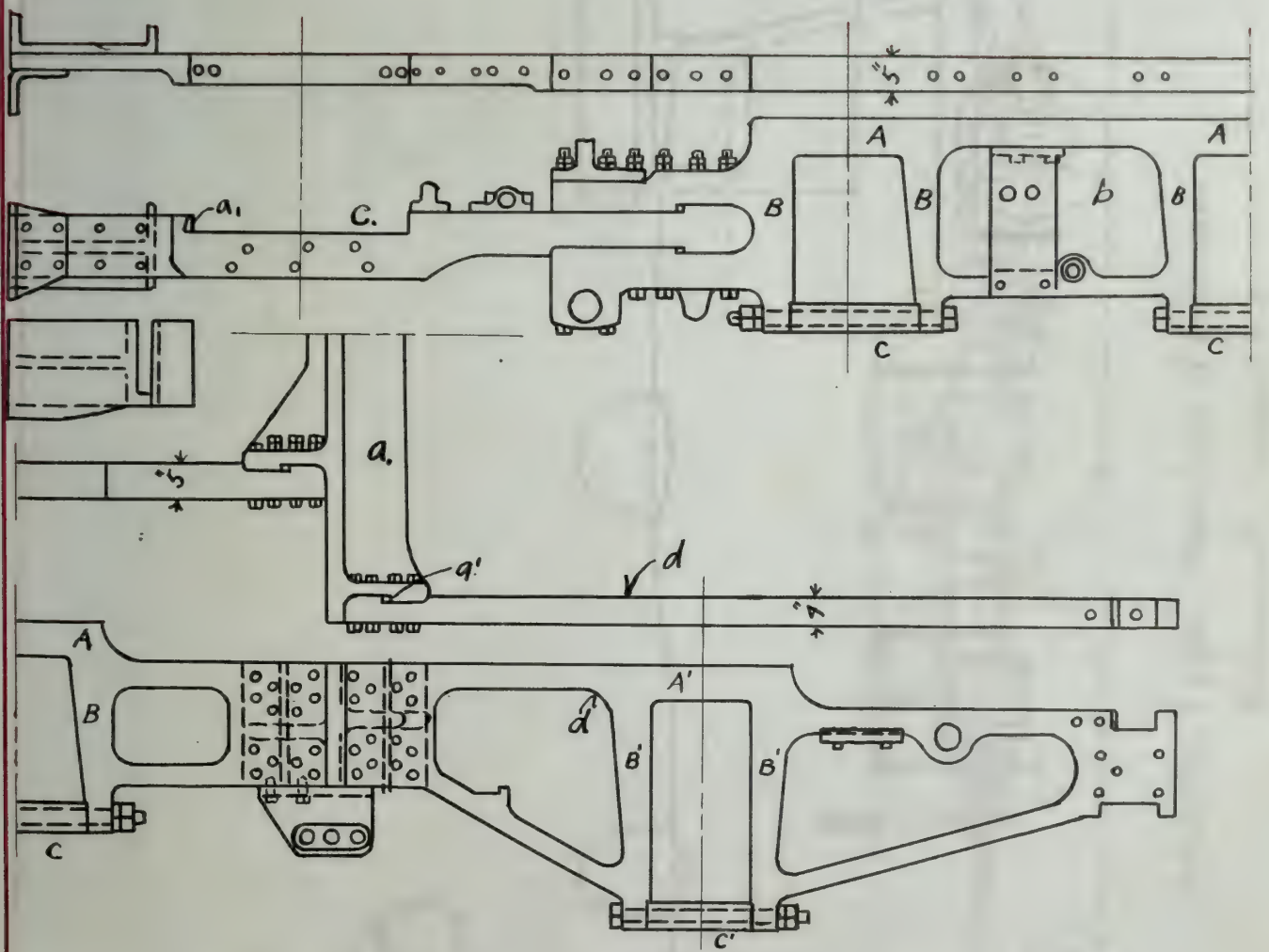
Frames for the consolidation locomotive are shown now pages 146 & 147. The top part or rail of the frame is straight its entire lenght. The figures show a top and a bottom rail clear to the front end. The front end of the fraw shows a top and a bottom part; one part coming on top of the cylinders and the other under it. The main frame of this type shows a straight

top clear back, which allows a wide fire-box to be used when the drivers are not too high. This style of frame is similar to those used on locomotives of the (2-6-0), (4-6-0), (2-10-0), and (4-10-0) types. The only difference being in the number of pedestal jaws for the driving boxes, and a few other minor details.

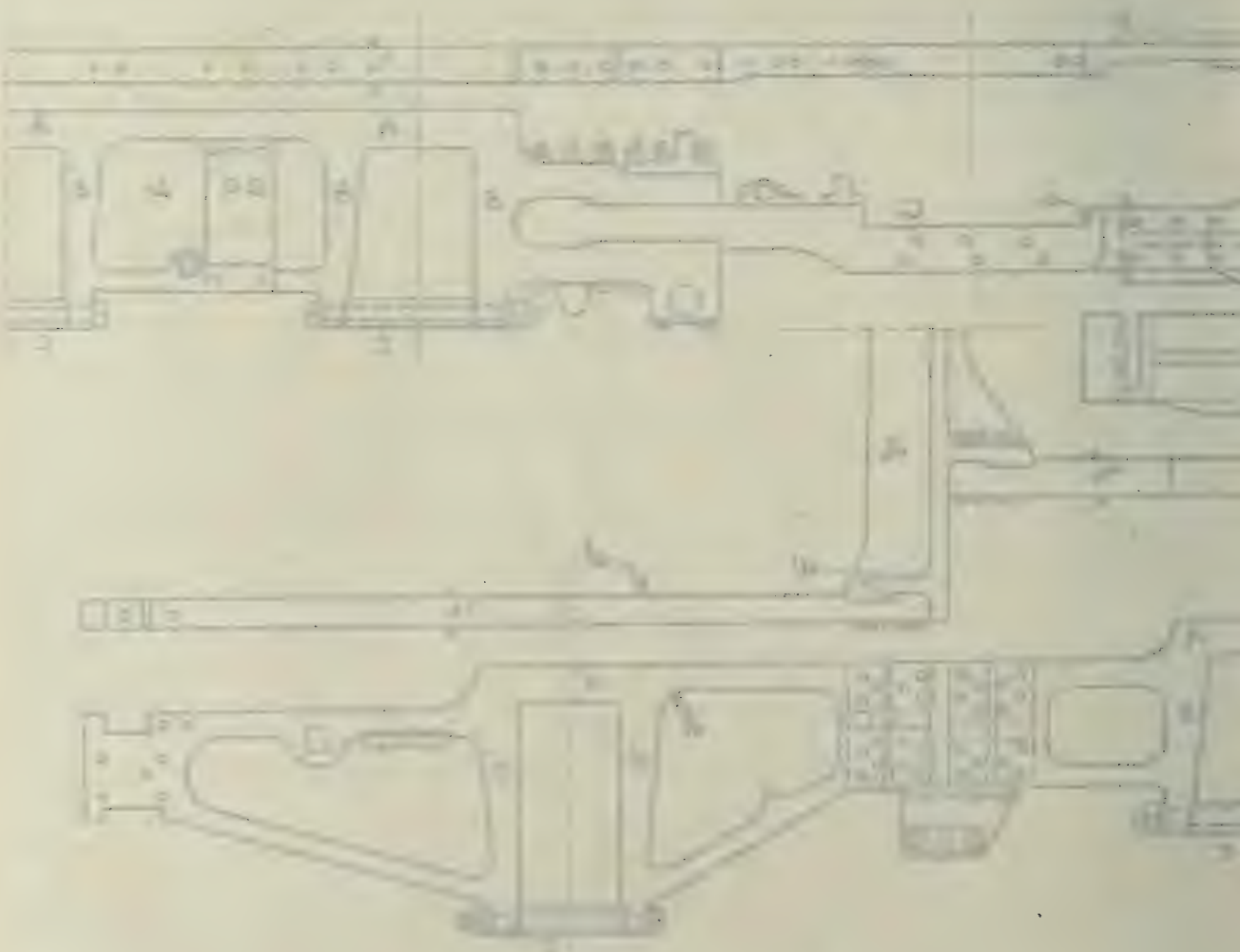
A number of other styles of frames are used, but their constructive features are similar to those already described.

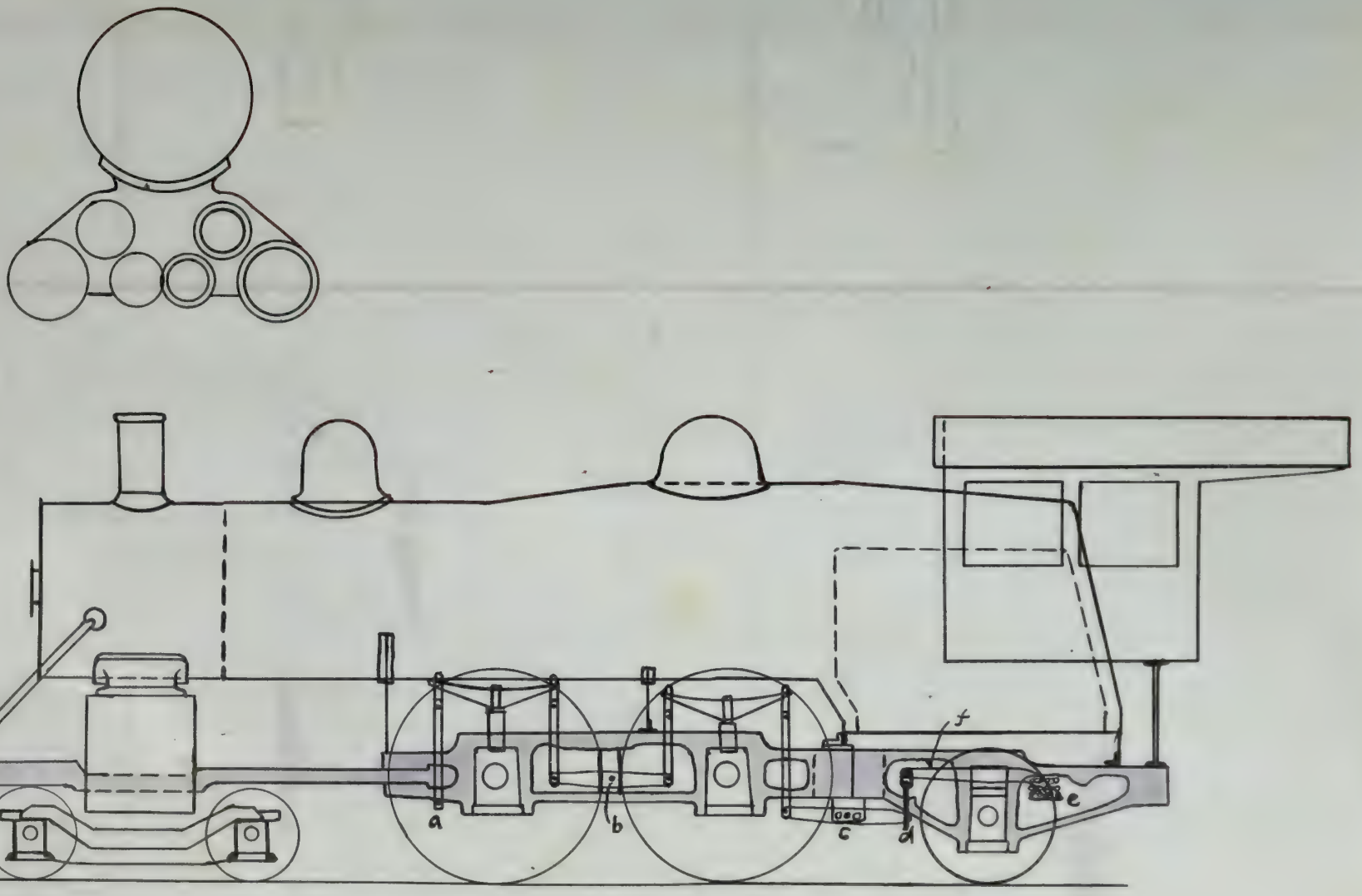
As is seen on page 144, the frames consists of a top rail A; BB the frame legs that form the pedestal jaws, which are braced by the bottom frame rail or brace; and C, the pedestal braces or binders. The pedestal brace binds the frame legs together, and prevents them from spreading, while at the same time it permits the wheels and boxes to be readily dropped out or in when neccessary. There are two forms of pedestal braces in general use; the thimble arrangement shown in fig. 1 and 2 on page 139, and the cap brace shown in fig. 3. The method of bolting together is also shown in these figures.

The frames are braced together at the top by the foot of the plate braces holding the boiler up,



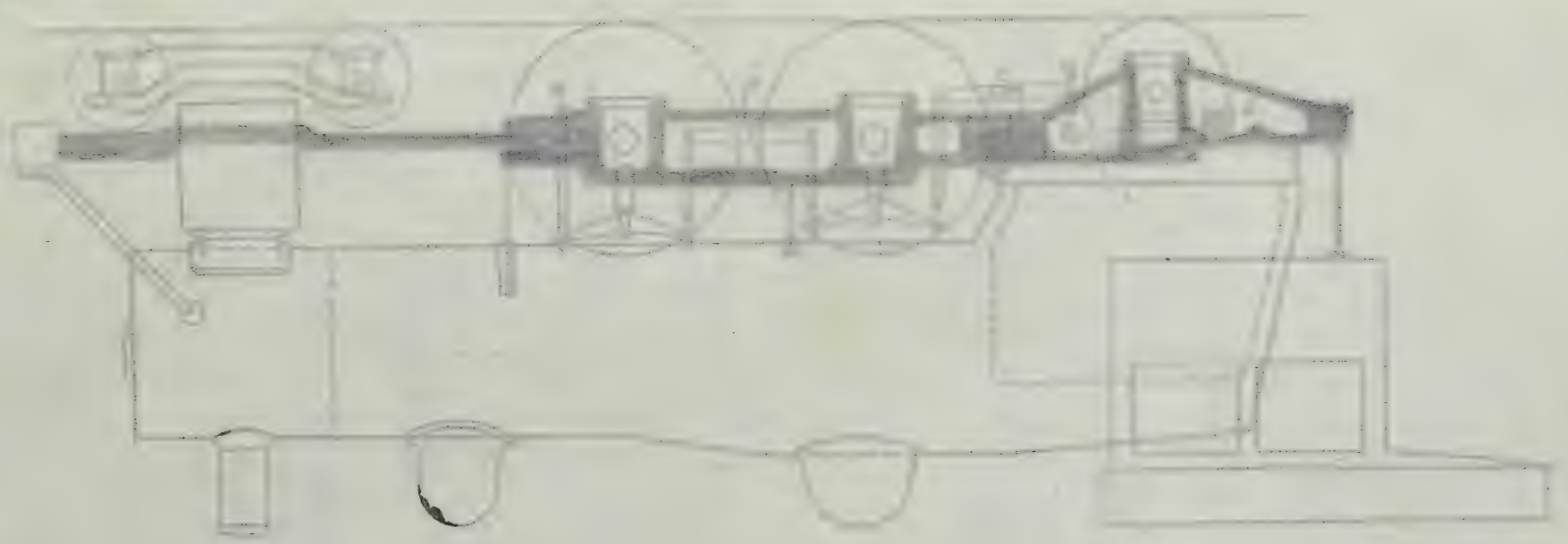
Frame For Atlantic Type
Pasenger Locomotive.

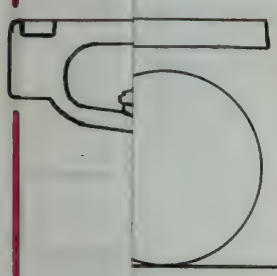


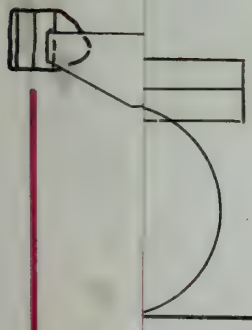


Atlantic Type, Vauclain 4 Cylinder

Balanced Compound.







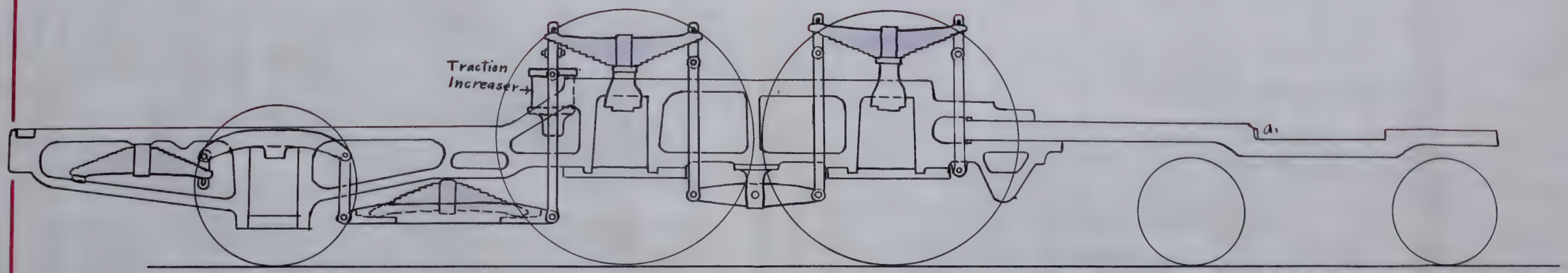


Fig. 1.

Frames & Carrying Gear, Atlantic Type Locomotive.

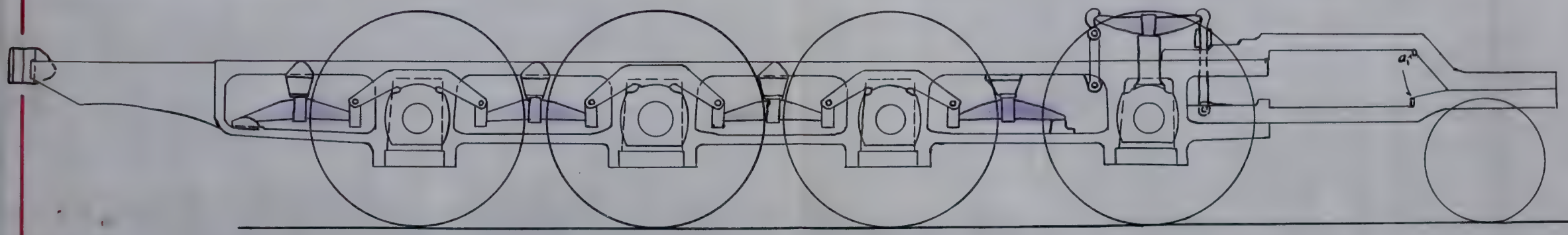
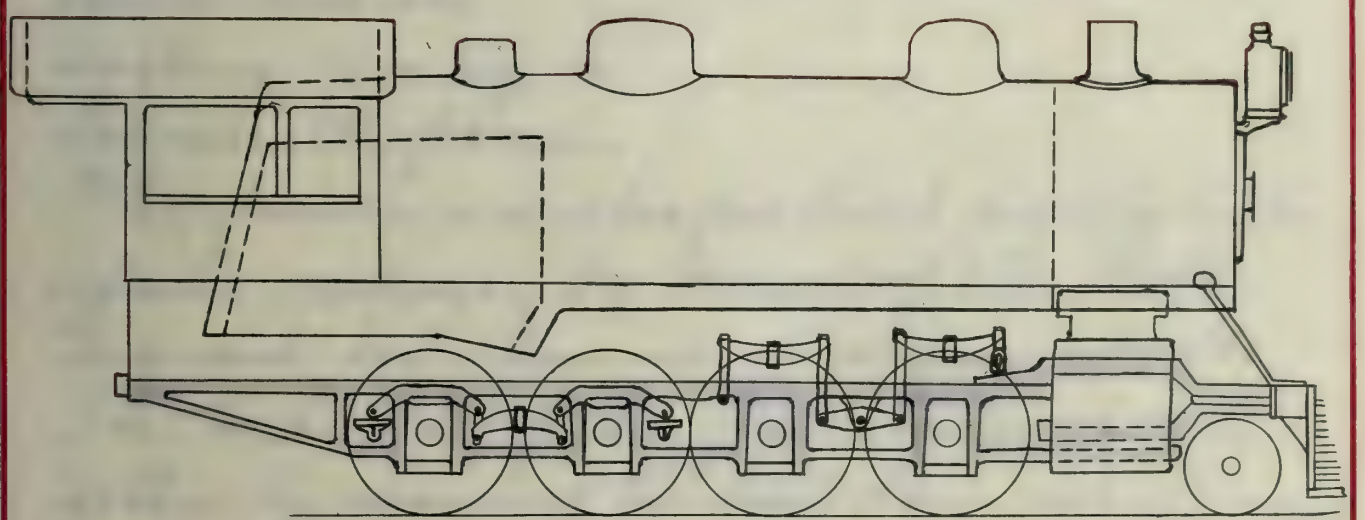
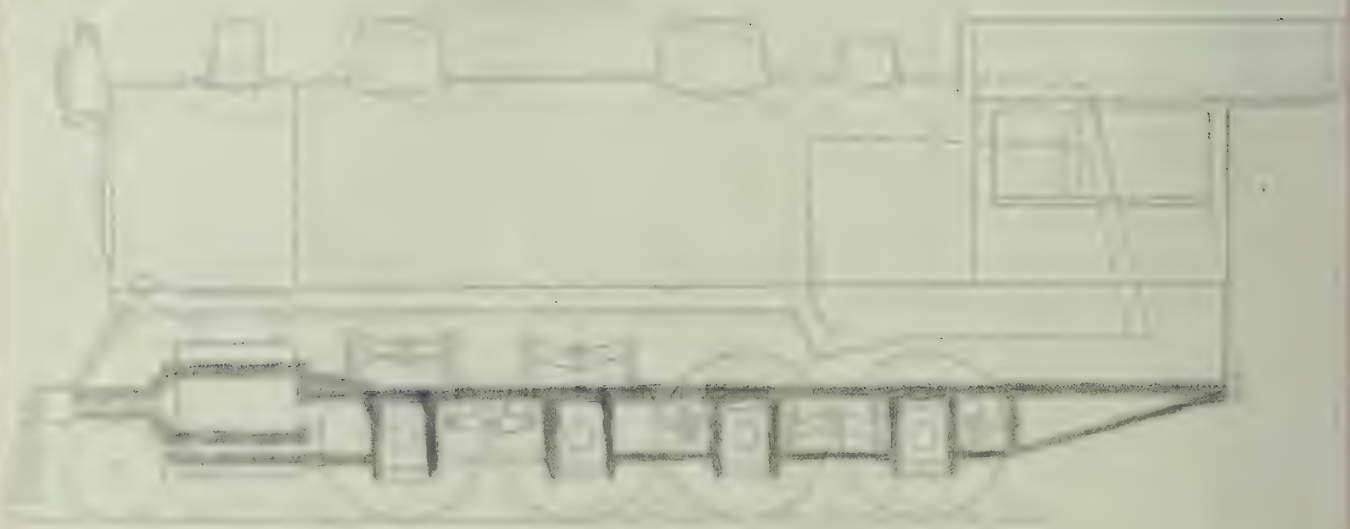


Fig. 2.

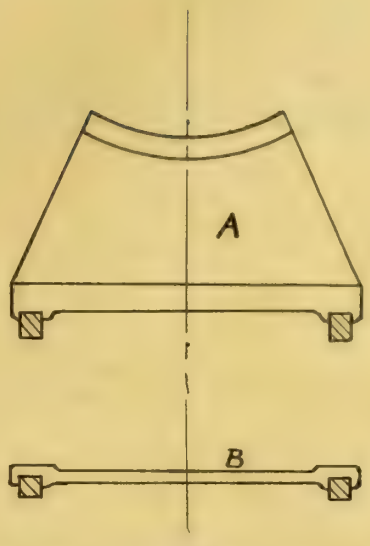
Frames & Carrying Gear of A Consolidation Locomotive.



Consolidation Locomotive.



and at the bottom by the cross braces. These braces are shown at A & B in the figure. The front ends of the front frames are held together by means of the bumper beams and its casting coming in between the frames.



Frame and Boiler Braces.

The frames are also fastened rigidly to the cylinder castings, by means fitted bolts, lugs and key shown at a' on pages 144+146. The back end of the frames are held together by means of the tail bar, which may be a steel casting, or it may be made of two bars containing the chafing or bumper casting in between them. If a steel casting is used, it contains the bumper casting in the same piece. This bumper casting contains the hole for the draw bar and its pin. Two chains are also fastened to the tail bar and are connected to the tender. These are called safety chains, and their purpose is

to prevent the engine and tender from coming apart in case the draw bar should become broken or disconnected in any manner.

8. Carrying Gear.

The frame of a locomotive carries all the weights of the various parts with the exception of the drivers, trucks, side rods, the rear end of the main rods, and the eccentrics and straps. This and the weight of the frame is in turn transferred to the journals by means of the carrying gear; so as to equalize the weight, and also carry the weight by means of springs. The purpose of the carrying gear is, therefore; to equalize the weight as desired between the journals of the drivers and trucks, and to have springs which will absorb the shocks occasioned every time the wheels pass over a bad rail joint, or a high or low place in the track.

The carrying gear consists of equalizing levers, springs, hangers, saddles, and many other pieces, depending on style of carrying gear and type of locomotive. The purpose of the equalizing levers is to equalize the weights

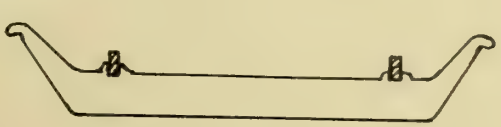
between the drivers or wheels. If no such devises were used, and if the frames were connected directly by springs to the driving boxes; every time a driver passes over a high spot it would tend to lift and carry the load of the other drivers of that side; also every time it dropped into a low spot it would tend to throw its share of the load on the other drivers. This not only would make the engine ride hard, roll, and pitch more than usual, but it would engine to such stresses as to neccessitate more frequent repairs to both track and engine. The purpose of the springs are to absorb shock and jars.

The hangers, saddles, pins etc. serve as a means of connecting the apparatus together. The figures shown on pages 145-147 illustrate different types of carrying gear used.

The method of attaching the pony truck to the main carrying gear is shown on page 131. This is done by means of the cross equaliger i connected to the truck equaliger e through the hanger h as shown in the figure. The four wheeled trucks are seldom, if ever, connected to the main carrying gear. This is not neccessary as the weight coming on the truck is equaliged between

the wheels by its own carrying gear, which consists of springs and levers as shown on page 127; again, the mechanism of the truck and its connection to the front end is such as to allow no means of equalizing the weight with the main carrying gear as with the two wheeled truck. The front truck equalizer of the pony type usually has three holes in the center casting shown at d, by which the weights on the truck may be changed slightly.

The drawings on pages 145 146 show the carrying gears used on a modern type of Atlantic passenger engine. The truck is independent of the rest of the carrying gear. As shown in the figure, the engine is supported at the truck and the points a, b, c, and e; these points coming on both sides except at the truck, where the weight comes on the center casting. The lever shown below connects the carrying gear of the drivers with that of the trailer trucks, which is used on locomotives



having wide trailer frames. This lever is used as a cross lever on which the side equalizers are attached as shown on the Atlantic type of locomotive on page 145. The heavy leaf springs rests on saddles as shown. These saddles are made of heavy bar steel in the form of a ⊓ which fit over the frame and rest on the driving boxes.

The drawings on pages 146 147 show the carrying gear as used on consolidation locomotives. As shown here the, the heavy leaf springs, towards the rear of the locomotive are placed in between the rails of the frame. This is done because there is no room for them above the frame, on account of interfering with the other parts of the locomotive. The truck is connected to the main carrying gear by the method shown on page 131.

Many other different forms of carrying gears are in use, more or less similar to those described.

9. Traction Increasers.

Traction increasers are used on many locomotives. They consists of cylinders, which are worked by compressed air, the pistons being connected by means of levers

to the carrying gear. This operates the equalizing levers of the trailing truck, so as to leave little if no weight on the trailers. This is done in starting the locomotive, when it is necessary to have a very high tractive power, or it is used on very steep grades and slippery tracks. The upper figure on page 146 shows one position of placing the cylinders. Other locomotives have different arrangements to increase the tractive power, but all use air cylinders working on the trailer equalizing gear. This arrangement can also be placed on the front pony truck equalizing gear which is connected to the main carrying gear, but is seldom used.

Traction increasers can only be used on locomotives having trailers, or front trucks which are equalized with the main carry gear.

1. Air brakes.

Air brakes are used on a locomotive, so as to faciliate an easy and quick means of stopping the train. This is required by law in this country, for without this valuable apparatus, it would not be safe to use the high speeds that are used in the operation of trains.

The apparatus as applied to a locomotive consists of an air pump, which is generally placed on the side of the boiler ahead of the cab. This pump is usually placed on the left side, although, it may be, and is placed on either side. The steam is taken from the steam box which also supplies the steam for the injectors, blower pipe, steam heating and the lubricator. The exhaust is lead to the front end.

The air is stored in the main reservoir for use in the train line and the brake cylinders of the locomotive; however, it is passed through the auxiliary reservoir first so as to allow the steam (caused from heating the air in compression) to condense, so as to drain the water from it before using it in the train line. These air drums are

fastened under the running boards along the side of the boiler. Pipes leading from the main drum to the engineers valve in the cab near his seat and thence to the train line and locomotive brake cylinders complete the air piping for this apparatus. The brake cylinders are placed at the rear, or else in front of the front drivers. To the pistons, or their rods are attached levers etc. which operate the locomotive brake rigging. This rigging is applied to all the drivers and the trailers, but is not usually attached to the front truck.

2. Sanders.

Every locomotive is fitted with a sanding apparatus, so as to prevent the wheels from slipping on the tracks, when the latter are in a slippery condition. This apparatus consists of a large iron box which is fastened to the top of the boiler; sand pipes leading to the rail so as to distribute the sand on the rail complete this apparatus with the exception of the levers that operate the valves in the sand box. Nearly all modern

locomotives now use an air blast to force the sand from the sandbox, if it will not flow freely from any cause. This air is dilivered at the valve and forces the sand to run down the pipe to the rail.

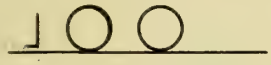
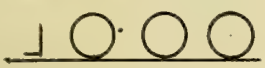
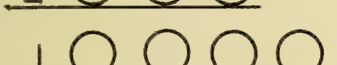
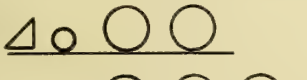
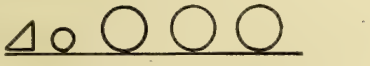
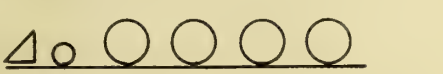
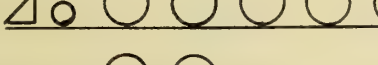
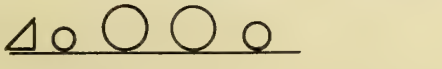
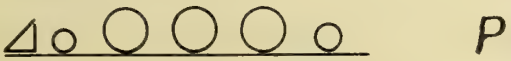
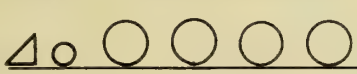
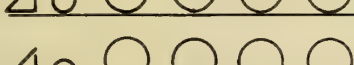
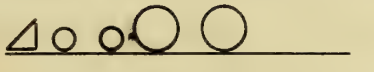
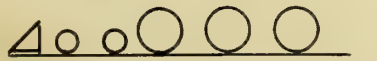
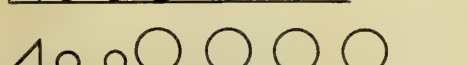
3. Electric Headlight.

On many of the modern passenger locomotives now in use, an electric headlight is supplied. This gives a much better light than the old style of oil light. The apparatus consists of an electrical outfit, consisting of a dynamo run by a steam turbine. The turbine and dynamo are direct connected, and are placed above the boiler just ahead of the cab. This outfit furnishes the current for the head light and the numerous incandescent lights used about the cab for lightening the various gauges, etc.. On other locomotives, these various lights are given by oil lamps.

Other miscelaneous apparatus that might be mention are: bell and automatic bell ringer, whistle, pilot, running boards, draw bars, cab, and tenders; however, the uses of these articles are well know as well as their construction

Classification of Locomotives.

Locomotives are classified according to wheel arrangement. The following table giving the wheel arrangement and the names of the different types.

Type	Wheel Arrangement	Name	Total Wheels.
0-4-0		4 Wheel Switcher	4
0-6-0		6 " "	6
0-8-0		8 " "	8
2-4-0		4 Coupled	6
2-6-0		Mogul	8
2-8-0		Consolidation	10
2-10-0		Decapod	12
2-4-2		Columbia	8
2-6-2		Prairie	10
2-8-2		Mikado	12
2-10-2		Sante Fe	14
4-4-0		American	8
4-6-0		10 Wheel	10
4-8-0		Mastodon	12
4-4-2		Atlantic	10
4-6-2		Pacific	12
0-6-6-0		Mallet Coumpound	12

1. Remarks on Different Types of Locomotives.

Of the different types of locomotives shown on page , the following are used to a great extent:

0-4-0 type for light switching service.
0-6-0 " " heavier " "
0-8-0 " " the heaviest " "
2-6-0 " " light freight and passenger service.
2-8-0 " " heavy freight service and heavy grades.
2-10-0 " " " " " " " " " .
2-6-2 " " " " and passenger service.
2-8-2 " " " " service and heavy "
2-10-2 " " " " " " " "
4-4-0 " " light " and passenger service.
4-6-0 " " " " " " "
4-8-0 " " heavy " service and heavy grades.
4-4-2 " " fast passenger and mail service.
4-6-2 " " heavy fast " service.
0-6-6-0" " the heaviest freight service on heavy grades

The types not mention above are not used extensively. Of the above types, the 4-4-0 is the old type of locomotive that was

used very extensively a few decades ago. This engine is still used quite extensively on branch lines and for light freight and passenger service on the main lines. Many of the locomotives of this class in use to day are the old locomotives which were the principal locomotives in thier time. They have now been superseded by heavier locomotives, except where the service is light. For light service no better locomotives are to be had. The drivers are large enough to give a high speed with a comparatively low tractive power. They also give little trouble from breakages etc.

The 2-6-0 is an old type of locomotive and is larger than the 4-4-0 type having a higher tractive power it was much better for heavier service. It was used for this class of service when it first came out, but now it is used for light service only. The 4-6-0 type which is similar to this with the exception of the front truck and the mogul type are now used quite extensively for branch lines and weigh freight service on main lines. They are also used quite extensively on local passenger trains.

The 2-8-0 type was the first heavy freight engine having a high tractive power introduced in this country. The wheels are comparatively low (not exceeding over 60 inches); therefore with the large size cylinders and boiler used makes it a good freight engine on heavy grades. It is not so well adapted for light grades and fast service, since the wheels are too small so it cannot maintain speed. It is one of the most widely used freight locomotives for heavy service.

The 2-6-2, or the Prairie type of locomotive first came out in 1900. It makes a good fast freight locomotive, and is used quite extensively for heavy passenger service. The large wheels used give it ~~a~~ high speed having a comparatively high tractive power making it a good first class freight engine. It is much more economical than the consolidation locomotive for heavy freight service, as has been determined by experments by the Chicago, Burlington, an Quincy Railroad Company. This is no doubt due to the much larger divers used on the former than the latter. The above road uses the Prairie (2-6-2) type

for nearly all its heavy freight service, which is a good indication of its adaptability for this class of service. Many of the larger locomotives have a much higher tractive power, but their drivers are comparatively low with respect to those used on the (2-6-2) type that they are much slower.

The (4-6-2) Pacific type was introduced for heavy passenger service. The success of the Atlantic (4-4-2) type for fast passenger service led to the introduction of the above type. The higher tractive power combined with its large drivers adapts it particularly for heavy and fast passenger trains.

The Mallet compound shown on page 165 is the heaviest locomotive made up to the present time. Its principle diamensions can be seen from the following plotted values on pages

Of the other heavy types of locomotive, it is known that most of them are designed advised for heavy grade service.

The following article on "Locomotive Progress" shows the modern tendency of locomotive construction.

2. Locomotive Progress.

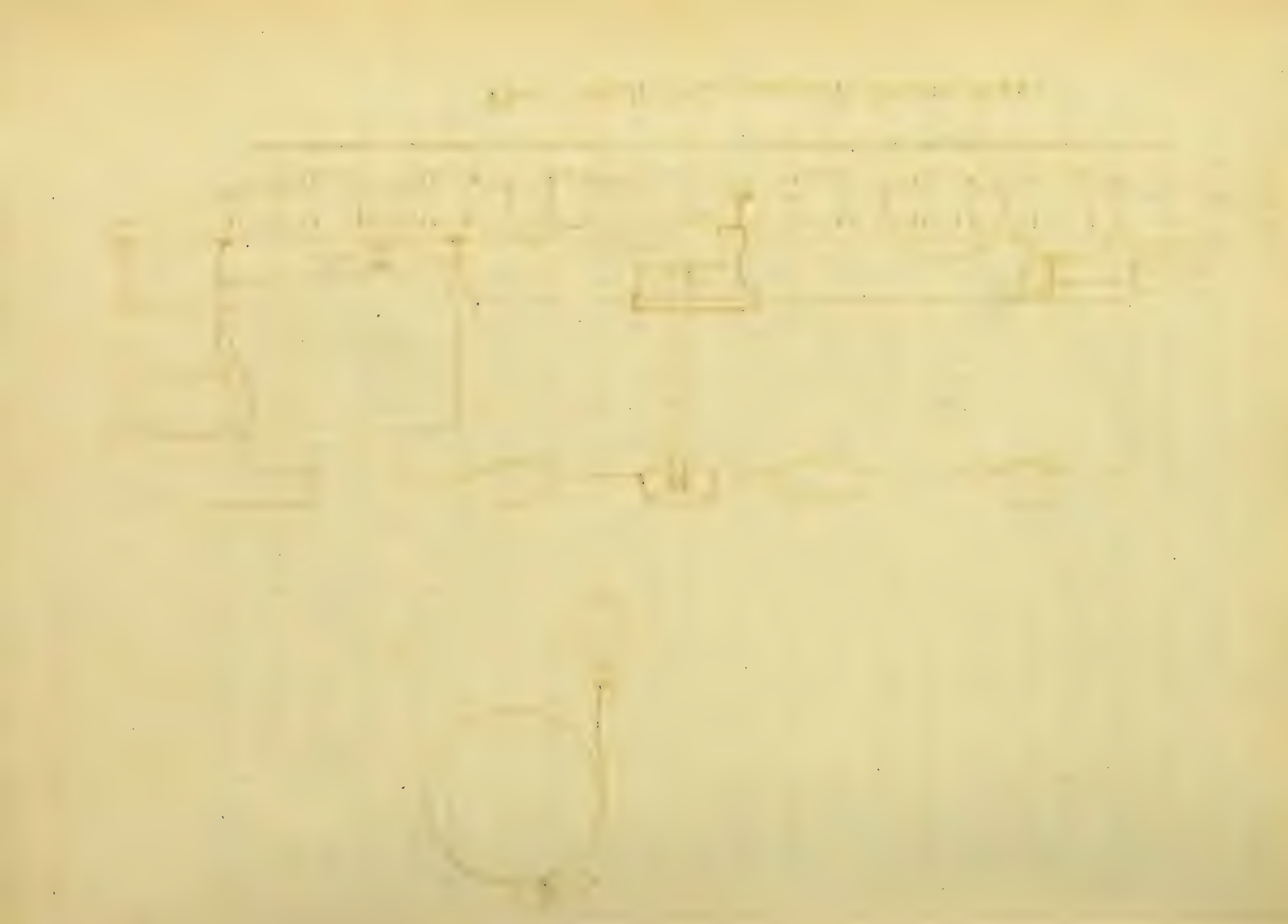
The demands on both passenger and locomotives have increased very greatly since the early locomotives were introduced. The locomotives since then have steadily increased in size until we now have the heavy locomotives seen today. The last ten years since 1895, the locomotives both freight and passenger have increased greatly in size and capacity, which has made neccessary some radical changes in their design and construction. Some types have reached their limits and others have been introduced to take their place. Very many different types have been introduced during this period; the principal ones of which are: the 10 wheeled type (4-6-0), the Mikado (2-8-2), the Prairie (2-6-2), the Pacific (4-6-2), the decapod (2-10-0), the Sante Fe (2-10-2), the Mastodon (4-8-0), the Mallet (0-6-6-0), and the Atlantic (4-4-2). The accompanying diagrams show graphically the progress which has been made with various types of both freight and passenger, bituminous coal burning locomotives with respect to their total weight, weight on

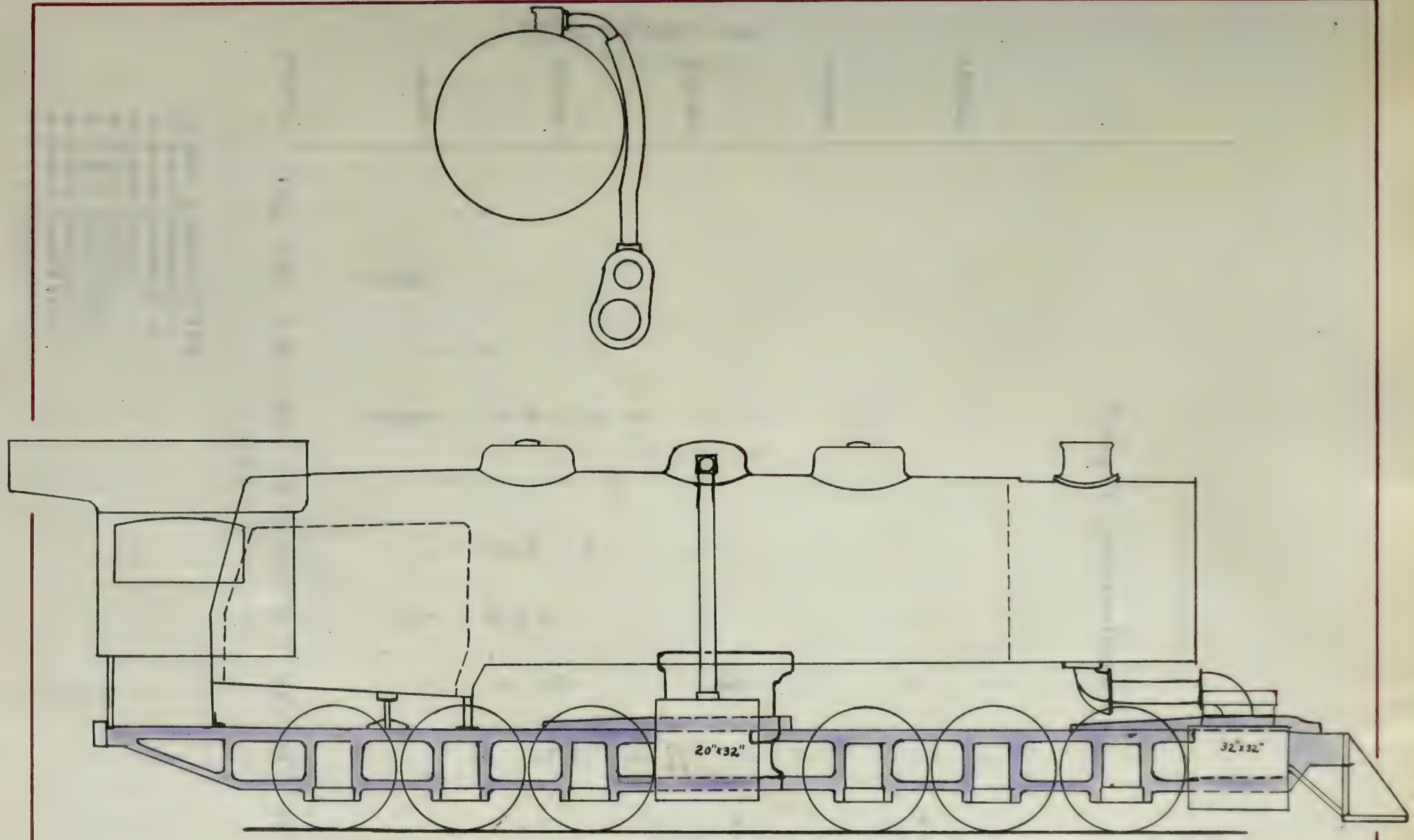
drivers, tractive power, heating surface and grate area. These different values, plotted on pages 166 to 175, were taken from the locomotives described in the "American Engineer and Railroad Journal" since 1895. The copy of this paper, which should have been in the library, for 1905 was at the bindery at the time this thesis was written so the locomotives for that year are not plotted. The locomotives plotted consists of the most notable locomotives which were built from time to time, and which have been described by the above journal. The data is taken from 62 passenger engines and 65 freight engines. These are all bituminous coal burning locomotives. Each type is represented by a different symbol, so that the progress made with each type may be traced.

The increase in the total weight has been steady and uniform, the lighter locomotives being replaced by heavier types. The main road engines of nearly all lines now consist of modern heavy locomotives, while the smaller ones have been discarded for use on side tracks and branch lines having light trafic. The weight on drivers has increased

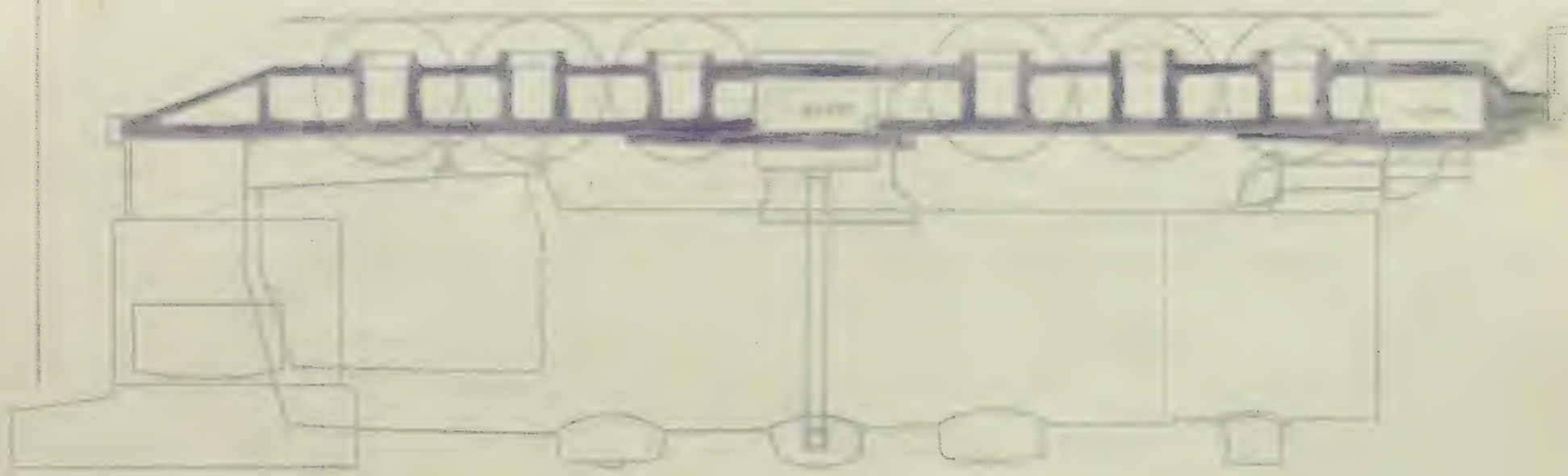
steadily with the weight of the locomotive. The tractive power has also increased steadily as will be seen on pages 170, 171. A comparison of the heating surface and grate area diagrams with that for the tractive power shows that they have increased at a faster rate than the tractive power. The about increase of grate area, which took place in 1900 and 1901, indicates the introduction of the wide firebox.

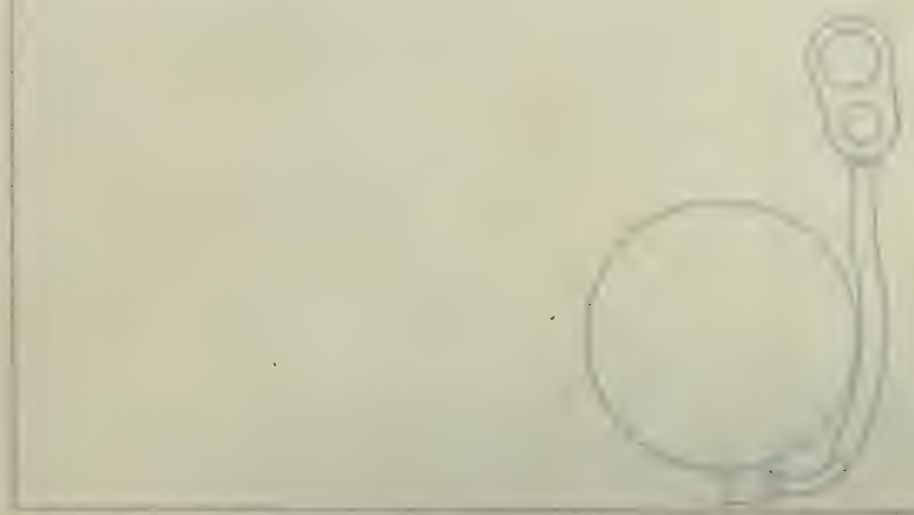
The largest locomotive yet built is the "Mallet compound" shown on page 165. As is seen this locomotive has no truck wheels and the high pressure cylinders are placed midway between the ends of the boiler. This was made thus to permit the frame of the locomotive to be made in two parts; that is the frames are connected together by a large pivot just ahead of the high pressure cylinders. This permits the locomotive to be used on short curves, which otherwise could not be used on them at all. The weights and other data for this locomotive can be seen on the plotted values given on the pages 166 - 175.

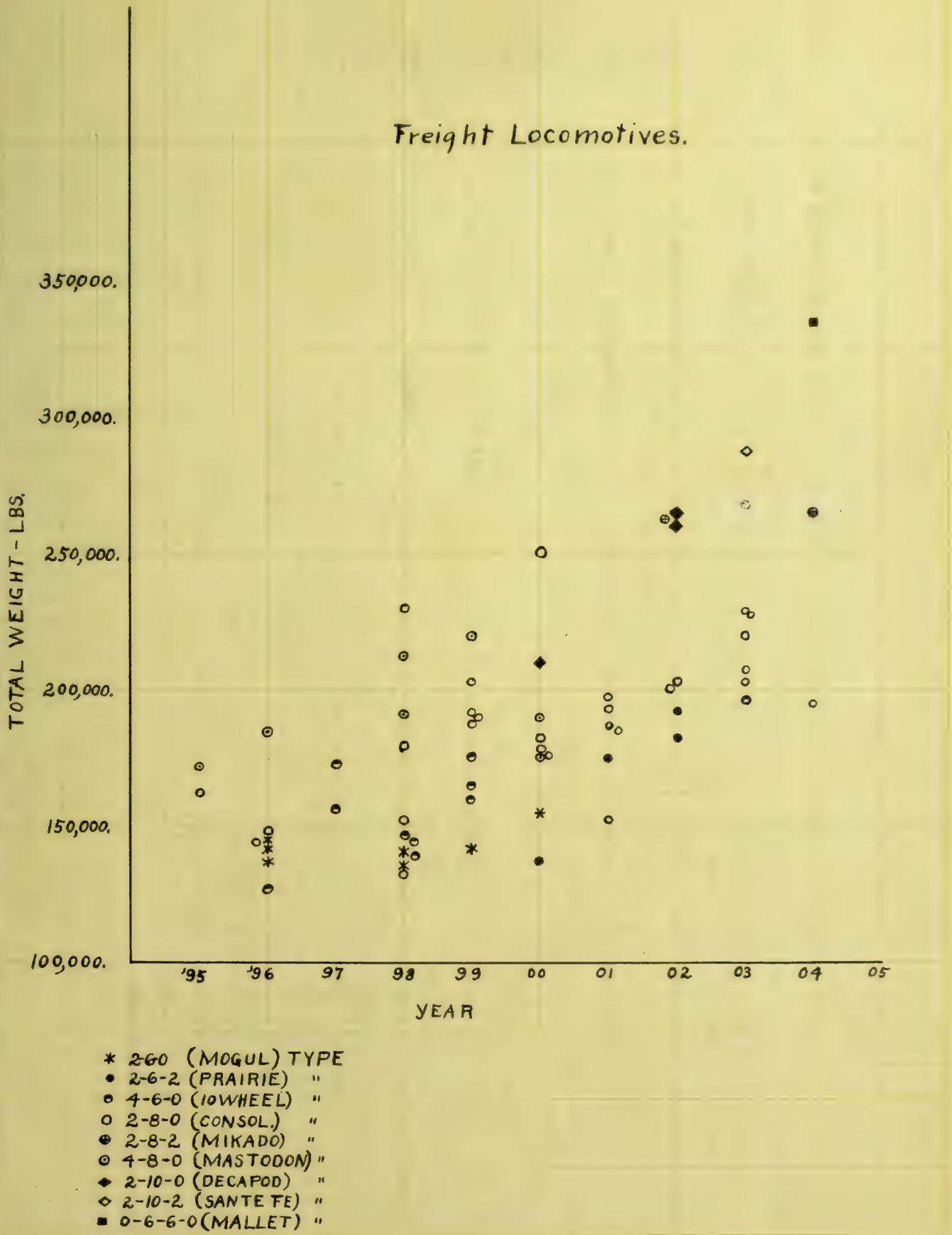




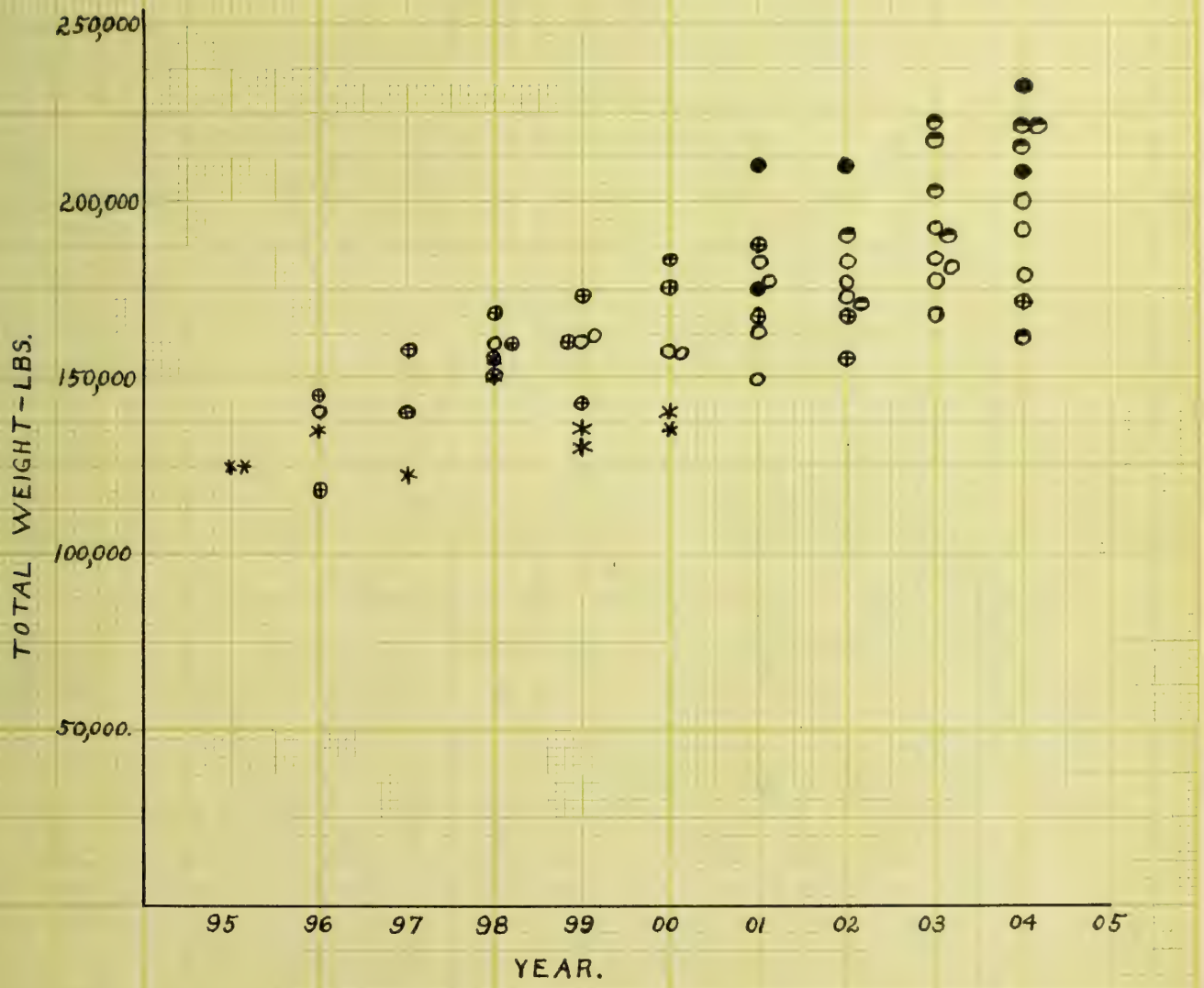
The Mallet Compound Locomotive.






Freight Locomotives.
350,000.
300,000.
250,000.
200,000.
150,000.
100,000.
TOTAL WEIGHT - LBS.
'95
'96
97
98
99
00
01
02
03
04
05
YEAR
* 2-6-0 (MOGUL) TYPE
• 2-6-2 (PRAIRIE) "
o 4-6-0 (10WHEEL) "
O 2-8-0 (CONSOL.) "
⊕ 2-8-2 (MIKADO) "
⊙ 4-8-0 (MASTODON) "
◆ 2-10-0 (DECAPOD) "
◇ 2-10-2 (SANTE FE) "
■ 0-6-6-0 (MALLET) "

Passenger Locomotives.



* 4-4-0 (8 Wheel) TYPE
⊕ 4-6-0 (10 ") "
○ 4-4-2 (Atlantic) "
● 2-6-2 (Prairie) "
◓ 4-6-2 (Pacific) "

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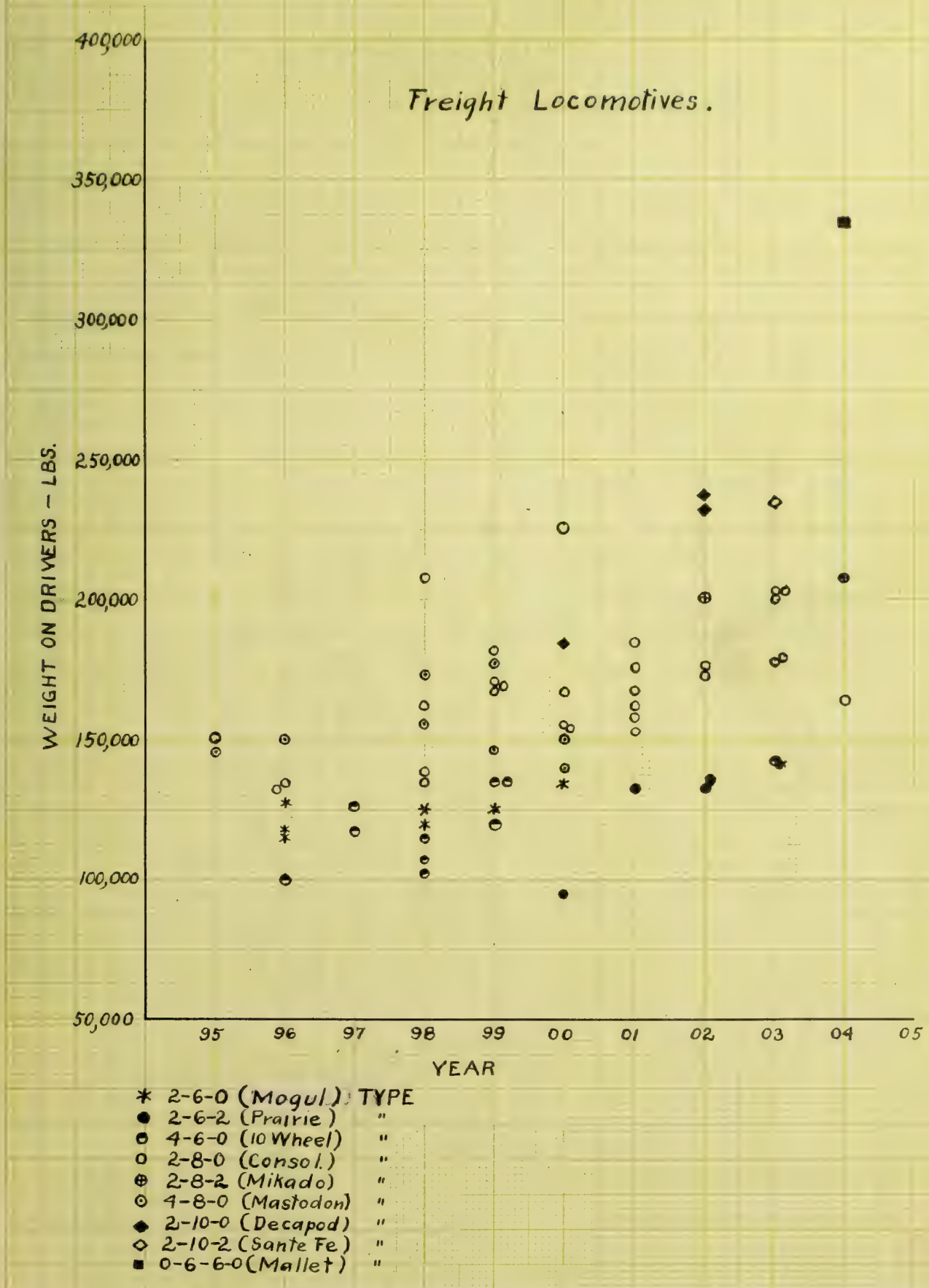
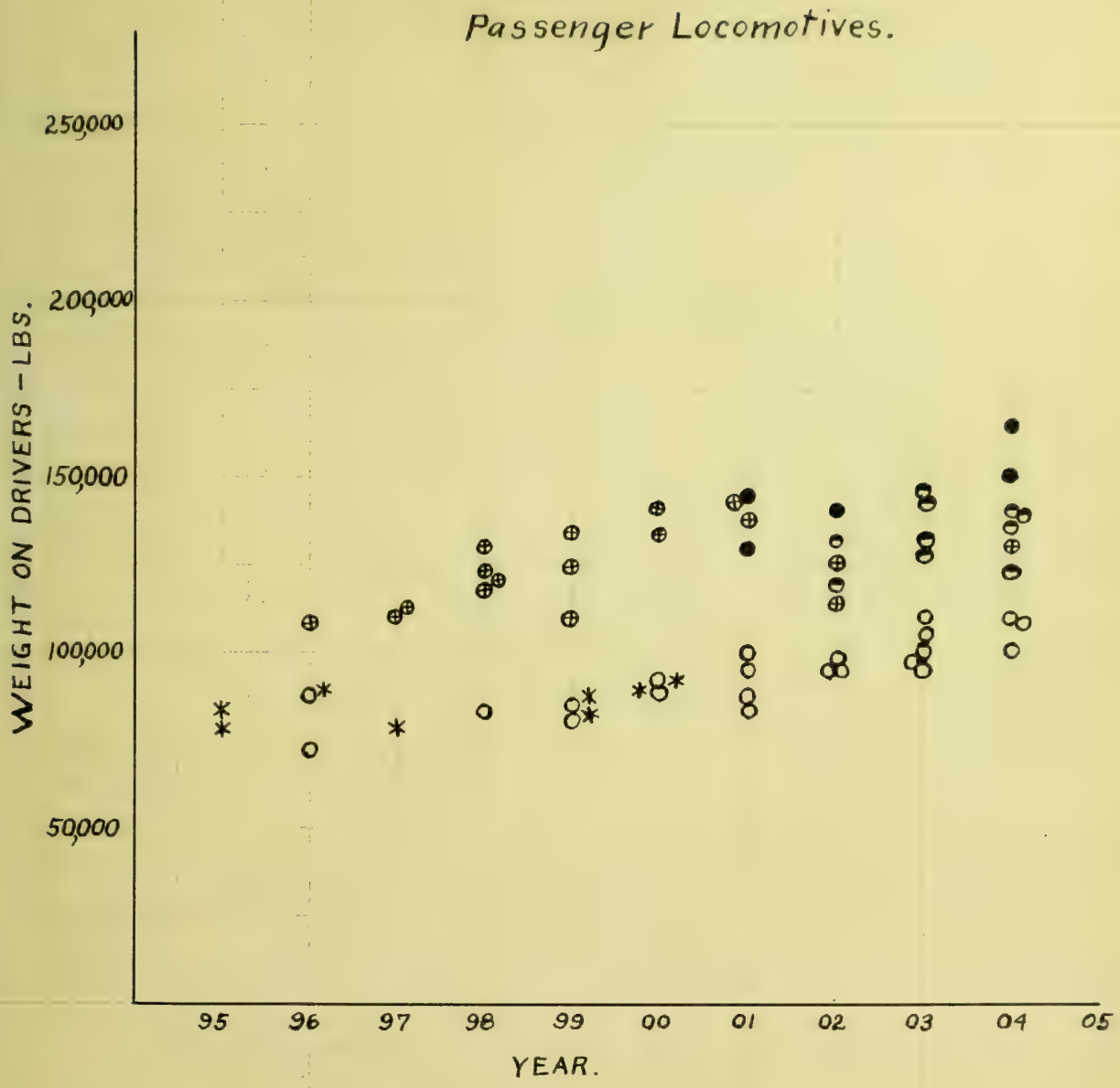
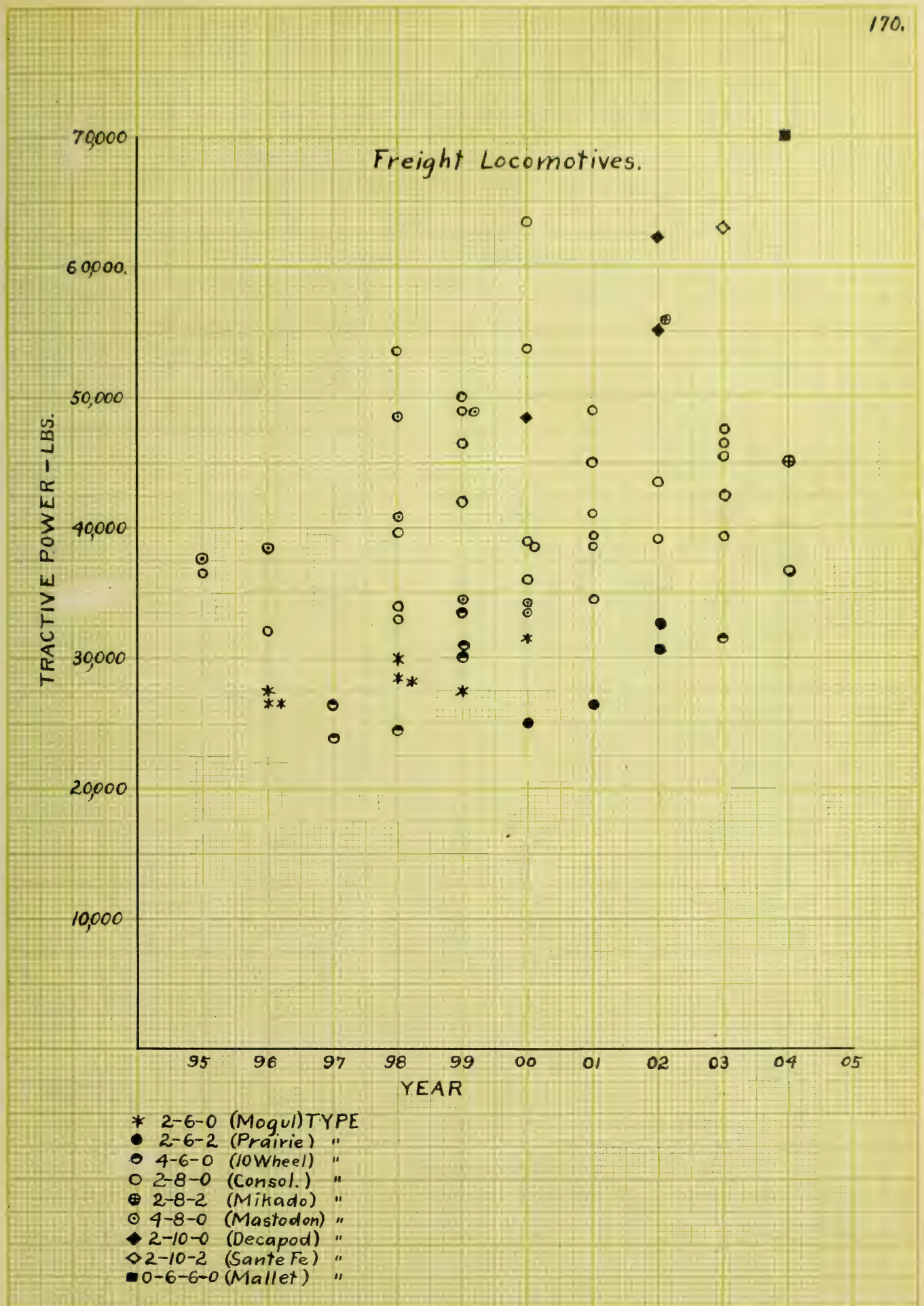

Freight Locomotives.
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
WEIGHT ON DRIVERS – LBS.
95
96
97
98
99
00
01
02
03
04
05
YEAR
* 2-6-0 (Mogul) TYPE
● 2-6-2 (Prairie) "
⊖ 4-6-0 (10 Wheel) "
o 2-8-0 (Consol.) "
⊕ 2-8-2 (Mikado) "
⊙ 4-8-0 (Mastodon) "
◆ 2-10-0 (Decapod) "
◇ 2-10-2 (Sante Fe) "
■ 0-6-6-0 (Mallet) "



* 4-4-0 (8 Wheel) TYPE
⊕ 4-6-0 (10 ") "
o 4-4-2 (Atlantic) "
● 2-6-2 (Prairie) "
⊖ 4-6-2 (Pacific) "



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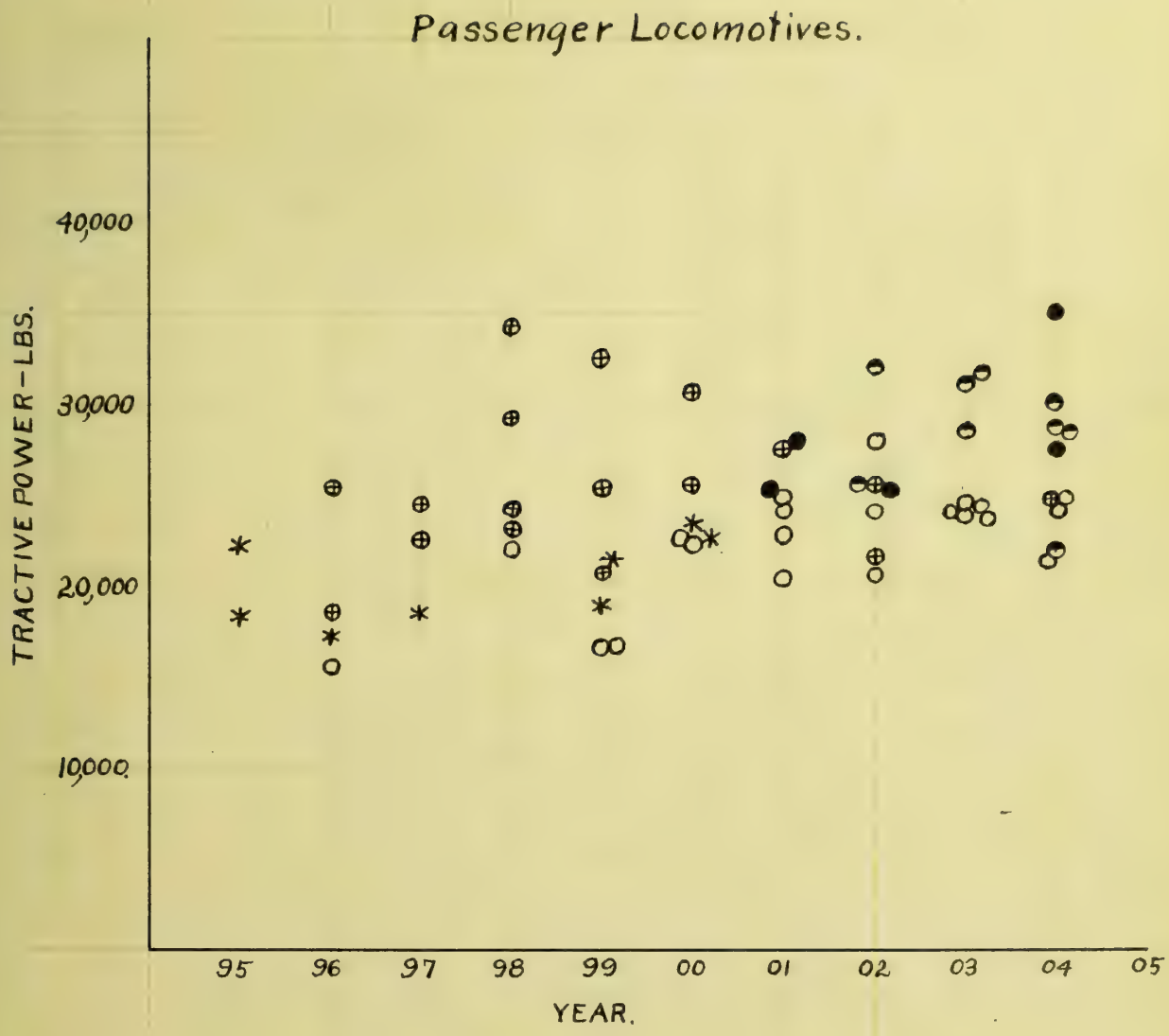
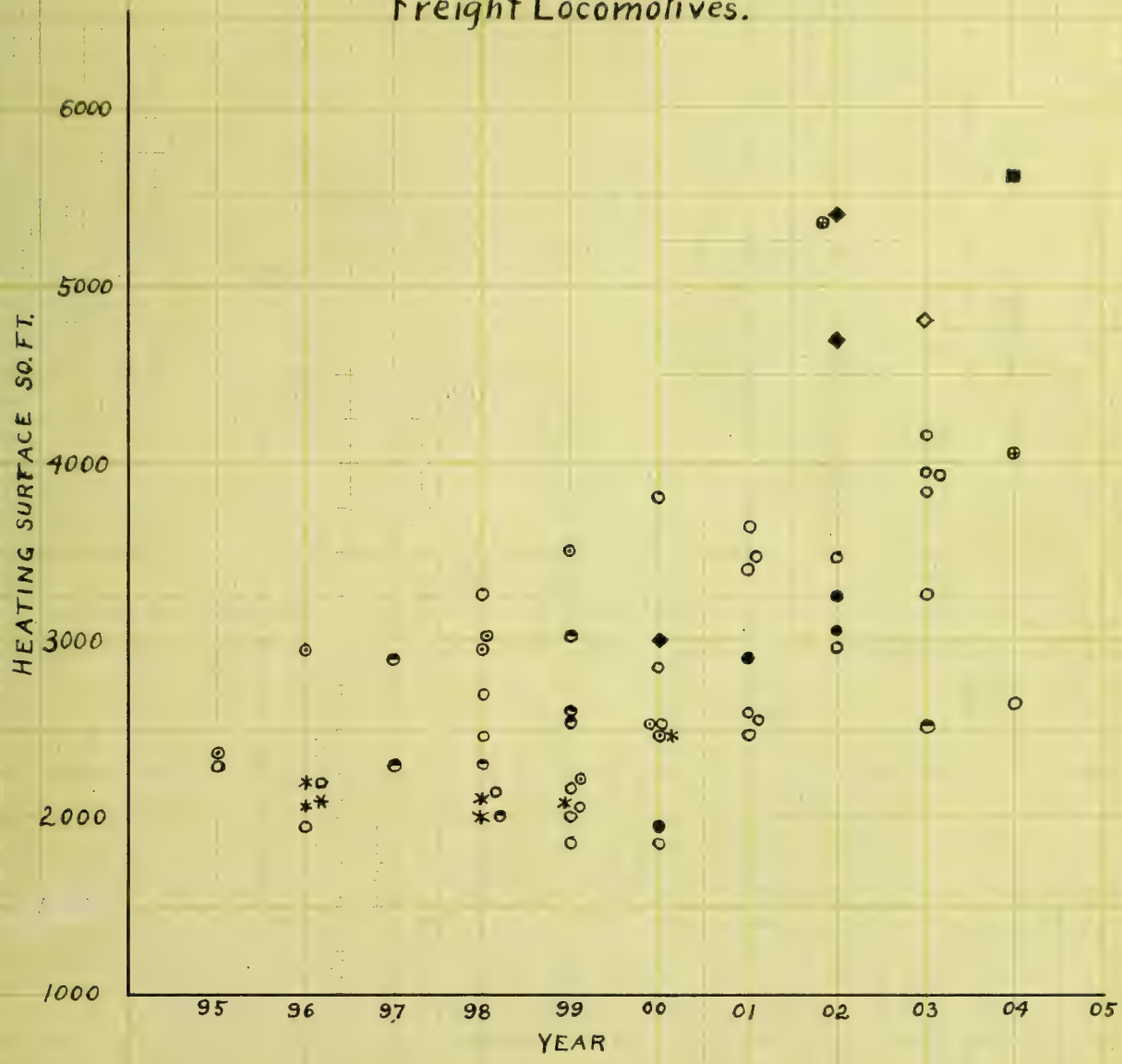
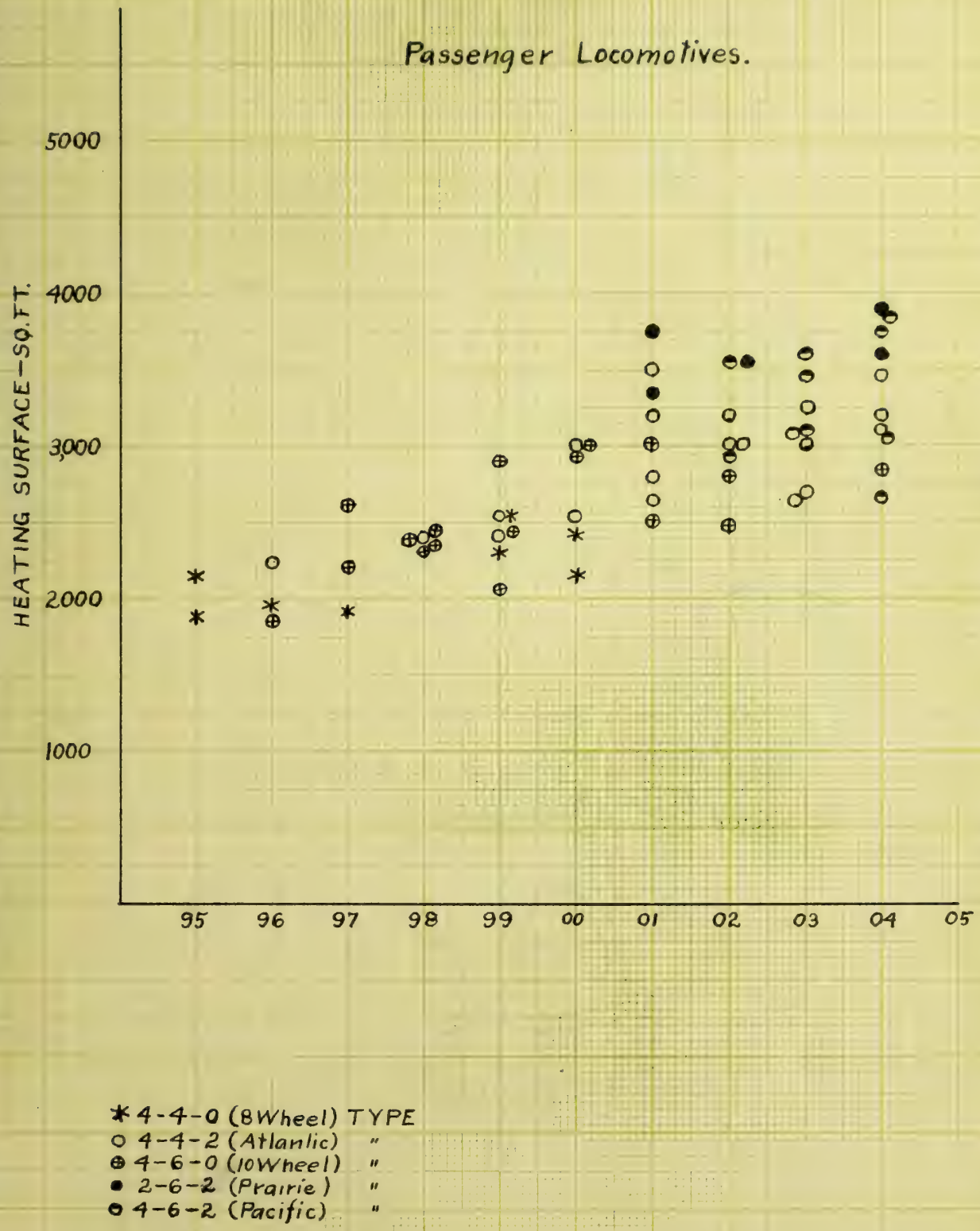

Passenger Locomotives.
TRACTIVE POWER-LBS.
40,000
30,000
20,000
10,000
95
96
97
98
99
00
01
02
03
04
05
YEAR.
* 4-4-0 (8 Wheel) TyPE
⊕ 4-6-0 (10 ") "
O 4-4-2 (Atlantic) "
● 2-6-2 (Prairie) "
◓ 4-6-2 (Pacific) "

Freight Locomotives.

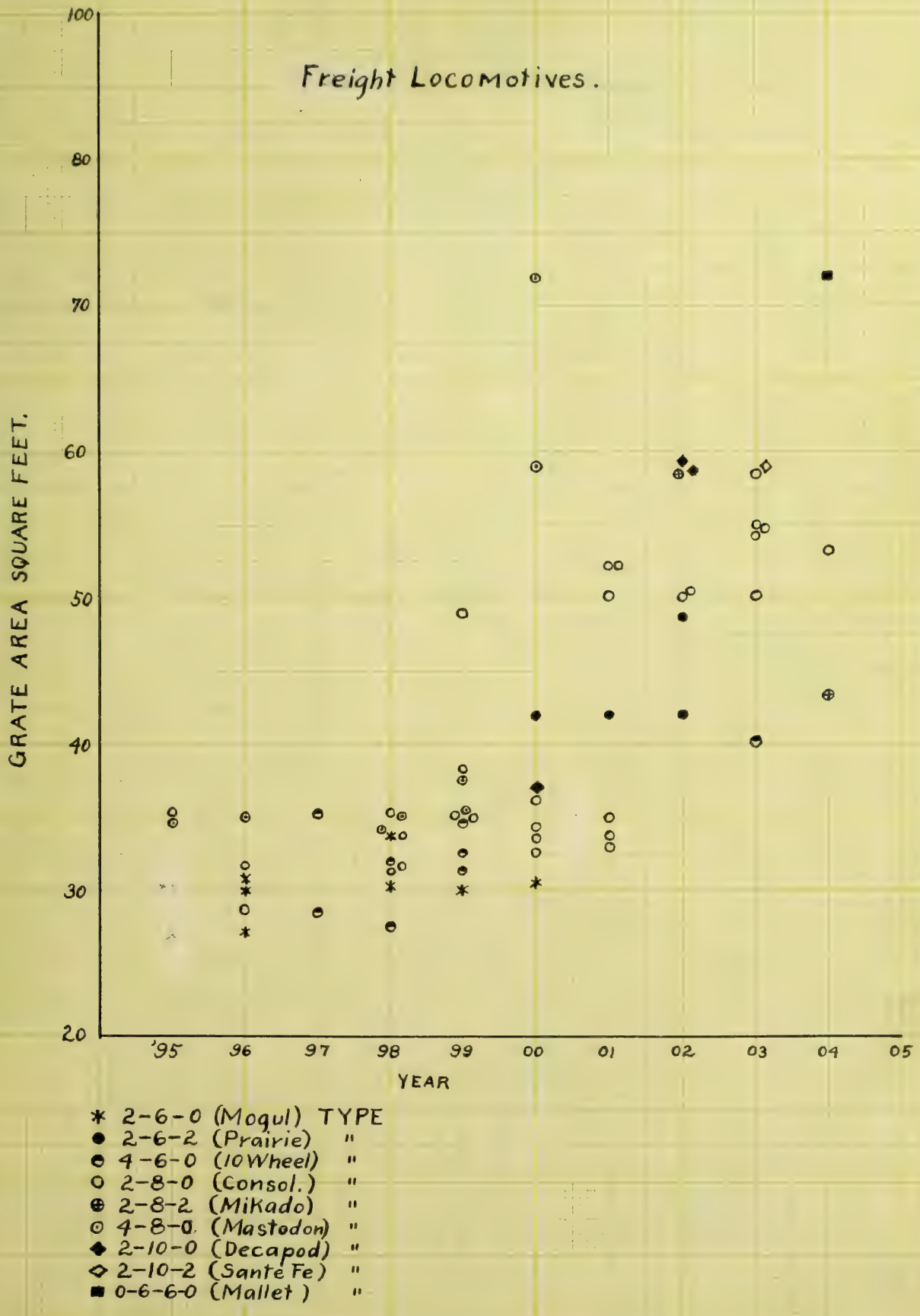


* 2-6-0 (Mogul) TYPE
● 2-6-2 (Prairie) "
⊖ 4-6-0 (10 Wheel) "
○ 2-8-0 (Consol.) "
⊕ 2-8-2 (Mikado) "
⊛ 4-8-0 (Mastodon) "
◆ 2-10-0 (Decapod) "
◇ 2-10-2 (Santa Fe) "
■ 0-6-6-0 (Mallet) "

EUGENE DIETZGEN CO. C



EUGENE DIETZGEN CO. CHICAGO



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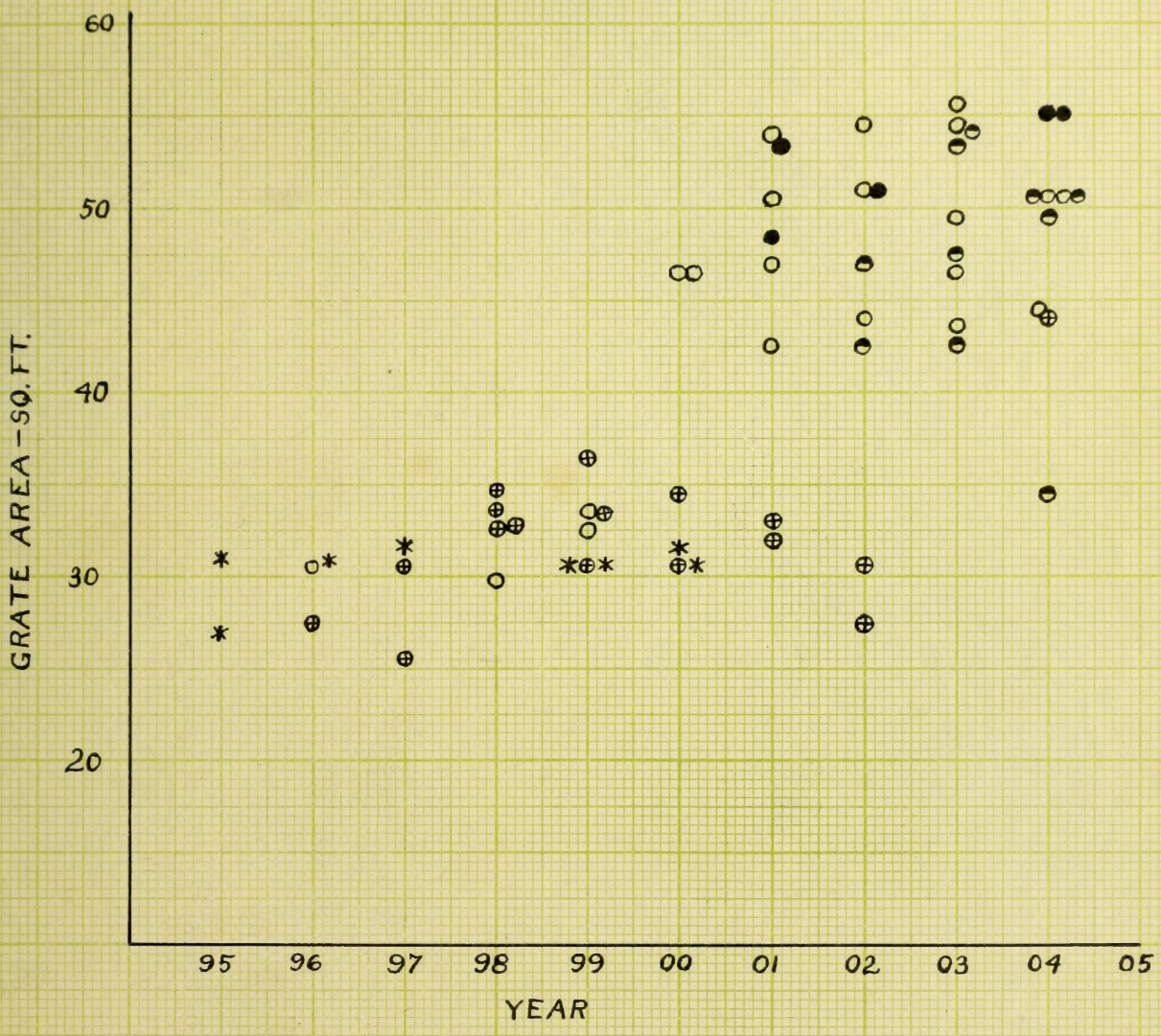
Passenger Locomotives.



* 4-4-0 (8 Wheel) TYPE
o 4-4-2 (Atlantic) "
⊕ 4-6-0 (10 Wheel) "
● 2-6-2 (Prairie) "
⊖ 4-6-2 (Pacific) "

EUGENE DIETZGEN CO., CHICAGO.

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